

AN EXPERIMENTAL STUDY OF THE EFFECTS OF LIGHT EXPOSURE TIME ON THE DEPTH OF CURING OF COMPOSITE RESIN

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광조사 시간이 복합레진의 온성 심도에 미치는 영향에 관한 실험적 연구

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동일한 광조사 시간으로 복합레진을 온성시키면 수복물의 깊이와 복합레진의 종류에 따라 레진이 완전히 온성이 되지 않는 경우가 있다. 본 실험은 광조사 시간이 복합레진의 온성심도에 미치는 영향을 규명하기 위하여, 무기충전체의 종류와 함량이 다른 4종의 가시광선 중합형 복합레진을 1.5.2.0.2.5 또는 3.0 mm의 시편 두께에 대해 20, 40, 및 60 초의 광조사 시간으로 각각 중합시켜, 그 상면과 하면의 록크웰 경도를 측정, 비교함으로써 다음과 같은 결과를 얻었다.

1. 4종 가시광선 중합형 복합레진 모두, 조사시간의 증가에 의해 그 표면경도는 더 증가하였으며 ($P < 0.001$), 그 증가량은 시편의 하면에서 더욱 컸다.
2. 시편 두께가 증가함에 따라 그 표면경도는 감소하였다. 이러한 영향은 시편의 하면에서 더욱 두드러진 양상을 보였다.
3. 가시광선 중합형 복합레진 상면의 경도는 하면의 경도에 비해 높았다. ($P < 0.001$)
4. 3 mm 시편 두께에서는 40 초 조사시간으로도 충분한 온성 심도를 얻을 수 없었다.
5. 시편 두께나 조사시간의 변화에 대해 Visio-Dispers 가 가장 민감한 표면 경도의 변화를 보였고, Durafill 이 가장 안정된 경도치를 나타내었다.

I. Introduction

Light-curing composite resins are being used in dentistry for the following advantages over the self-curing composite resins: (1) the single paste formulation requires no mixing – resulting in less porosity, (2) they have adequate working time, (3) they cure fast, and (4) they have better color stability since there is no amine accelerator present.

Recently composite resins cured by ultraviolet light have been replaced by those cured by visible light. The UV light-curing composite resins have some disadvantages, including irradiation, which can damage the eyes, and insufficient depth of polymerization.

On the other hand, visible light-cured composite resins have the advantages of a greater depth of cure than the UV light-cured resins initially used in dentistry¹⁾, and the wave length of the light is harmless for the patient and practitioner when the system is used properly. Moreover, it is able to be cured through the enamel layer.^{2,3,4,5)} Visible light-cured composite resins are currently in widespread use for restorative, preventive, orthodontic and cosmetic applications.

In composite resins with chemically induced polymerization, the reaction takes place almost uniformly throughout the bulk of material. However, it has been found that the degree of polymerization of visible light-curing composite resin is generally dependent on the thickness of the restoration.^{6,7)} Incomplete polymerization in the inner part of the restoration may lead to leakage of irritants into the pulp^{8,9)}, retention failure due to weakness of material, inability to obtain a smooth surface after polishing, or poor resistance to degradation in the oral environment.

The fact that composite resin that is not completely polymerized can induce harmful effects illustrates the great importance of knowing the depth of polymerization.

Thus, it is important to investigate to which degree a visible light-cured resin will polymerize by irradiation during a given time with a properly controlled light system. The depth of cure of these light-curing composite materials has been extensively studied using hardness data with the variation of restoration depth.^{5,10,11)} Factors affecting the depth of cure of UV light-cured composites were discussed by Cook⁶⁾. The dependency of polymerization of visible light-cured composites on light intensity and test methods was reported by Kilian.¹³⁾ Comparisons of the depths of cure and transmission coefficients of UV light-cured composites and visible light cured composites were reported by Tirtha et al.¹⁾ It has been shown that the depth of cure depends on the composition of resin, exposure time, intensity and wave length of light.^{2,3,4,5,10,11)}

However, the effects of composite type on in vitro depth-of-cure evaluation have rarely been addressed.

In this study, Rockwell hardness test was executed for the evaluation of depth of polymerization. The common hardness measurements, such as Knoop, are not so applicable in the evaluation of composites, since the inorganic dispersed phase is hard and the polymer matrix is soft. The small Knoop indentation therefore may be made in the inorganic or organic phases or part of each. A Rockwell hardness tester is appropriate to conduct the test on composite. Under a

relatively large indenter and light load, the steel ball rests on both the inorganic and organic phase and an overall resistance to penetration is obtained. ¹⁴⁾

The purpose of this study was to determine the effects of the variations of curing time, mold thickness and type of materials on the hardness values of the top and bottom surfaces of composite resin specimens used in depth-of-cure evaluation.

II. Materials and Methods

Four different type of composite resins based on the filler type were used. The types of composites were identified by the SEM feature. Prisma-Fil was selected as representative of traditional composite resin (large inorganic fillers). Lite-Fil A was selected as representative of hybrid composite resin (small traditional macrofillers with pyrogenic microfillers in matrix). Durafill and Visio-Dispers were selected as representatives of microfilled composite resins (Durafill as an microfilled composite resin with splintered prepolymerized heterogeneous particles and Visio-Dispers as an heterogeneous microfilled composite resin with agglomerated microfiller complexes). Composite resins are supplied in several shades. The materials designated as 'gray' by each manufacturer were tested in this study, since it is known that at equal irradiation time the light colored resins polymerize deeper than the darker ones. ¹⁶⁾

Cylindrical specimens were prepared in stainless steel molds which have 7mm internal diameter hole. If the diameter of the mold hole is smaller than 6mm optical outlet diameter of the light curing system, the wall of the mold will be somewhat reflective to the photo-activating light. Thus, this study used the molds whose hole diameters are larger than optical outlet of the curing system to get the effect of the mold material having translucency identical to that of the composite resin.

The mold thickness varied to 1.5mm, 2.0mm, 2.5mm and 3.0mm to assume the various thickness of the dental restoration.

During the polymerization, the test mold was placed on a polyester matrix strip which lay on white filter paper to simulate clinical conditions (Fig. 1).

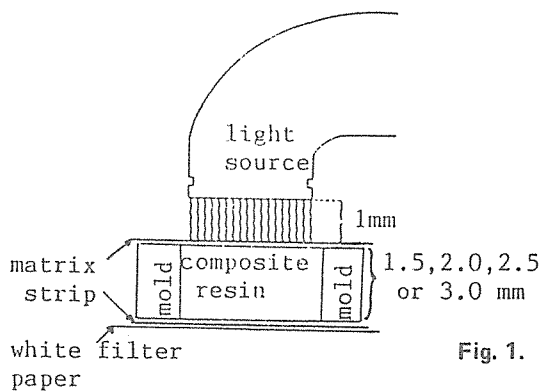


Fig. 1. Schematic diagram of experimental arrangement for specimen preparation.

The composite resins were dispensed directly from their containers into a cylindrical stainless steel mold. The mold was slightly over-filled with the resin. Another matrix strip was placed over the mold and a slight pressure was exerted on the slide glass to extrude any excess resin.

Prior to light activation, the slide glass was removed. The composites were illuminated through a polyester matrix strip for the destined amount of time from a distance of 1mm. Increased distance more than 1mm between light source and resin surface is influential on the surface hardness and uniformity.¹⁶⁾

A Translux visible light source (Kulzer Co., Hamburg, FRG) with a light-exit window of 6mm diameter was used to cure all the four materials.

The hardness number of top and bottom surfaces of four different composite resins were determined immediately after visible light curing with the variation of specimen thickness (1.5, 2.0, 2.5, or 3.0mm) and light exposure time (20, 40, or 60 seconds). Immediately after light curing, 15Kg load was applied with 1/16 inch ball indenter using Rockwell hardness tester (Page-Wilson Co., Connecticut, U.S.A.) on the center of each specimen. After 20 seconds the load was released automatically. Then the Rockwell hardness number was read.

Only one hardness reading on each specimen was obtained immediately after curing to minimize time variance in curing rate¹⁷⁾ and compacting effect which raises the hardness value during repeated indentation. Moreover, in clinical situations, it would be advantageous to know the hardness of composite restorations immediately after insertion since patients may begin mastication immediately following their dental appointments.

Five specimens were tested for each combination of variables.

III. Results

The composite resins used in this study were identified by SEM.

Prisma-Fil showed an SEM feature that it is composed of relatively large fillers and organic matrix (Fig. 2). Lite-Fil A consisted of traditional macrofillers and organic matrix dispersed with microfillers (Fig. 3). Durafill was composed of organic matrix dispersed with microfiller particles

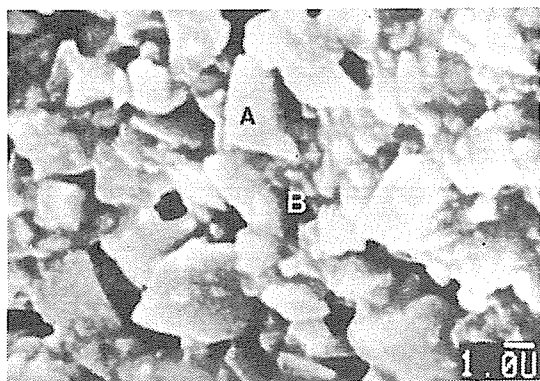


Fig. 2. SEM feature of traditional composite (Prisma-Fil): macrofillers (A) and organic matrix (B). (x5000)

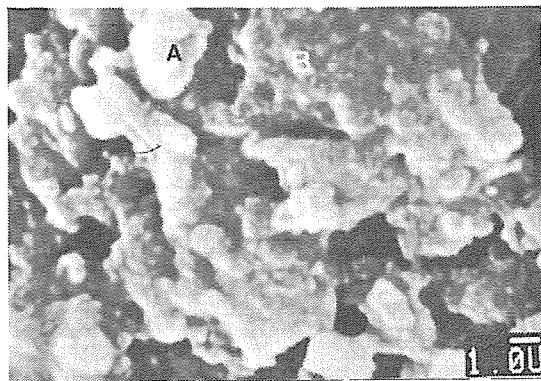


Fig. 3. Hybrid composite (Lite-Fil A): traditional macrofillers (A) and microfillers in matrix (B). (x 5000)

and relatively large splintered prepolymerized particles which are made by polymerization of organic matrix with microfillers (Fig. 4). Visio-Dispers consisted of small, more compactly agglomerated prepolymerized particles and microfillers incorporated into organic matrix dispersed with microfiller particles (Fig. 5).

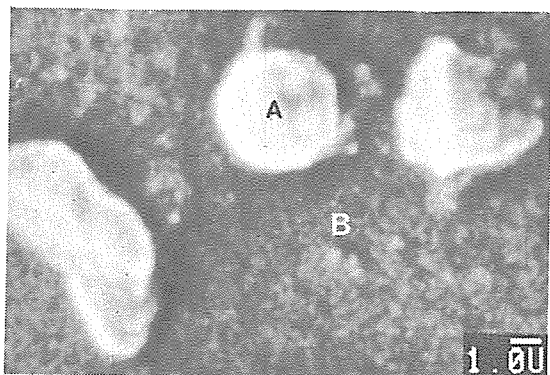


Fig. 4. SEM feature of inhomogeneous microfilled composite with splintered prepolymerized particles (Durafill): Splintered prepolymerized particles (A) and microfillers in organic matrix (B). (x 5000)

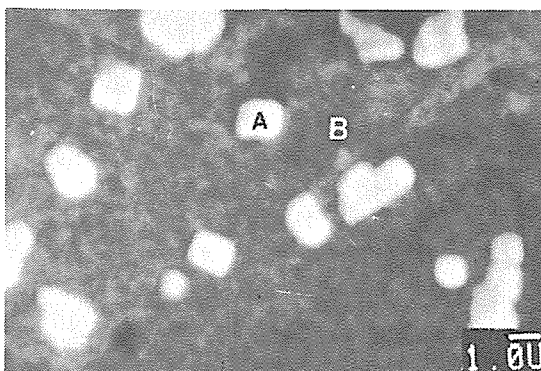


Fig. 5. Inhomogeneous microfilled composite with agglomerated microfiller complexes (Visio-Dispers): Agglomerated microfiller complexes (A) and microfillers in organic matrix (B). (x 5000)

The Rockwell hardness values in relationship to the type of material, measured surface, curing time, and specimen thickness were illustrated in Table 1 and Fig. 6, 7.

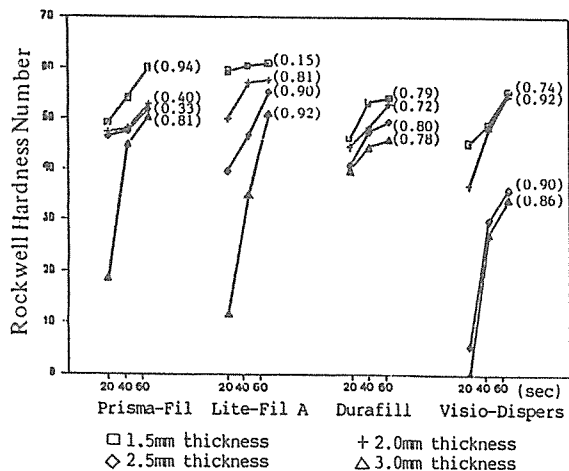


Fig. 6. Rockwell hardness values of composites in relation to the exposure time and specimen thickness. Correlation coefficients are in the parentheses. (Top surface)

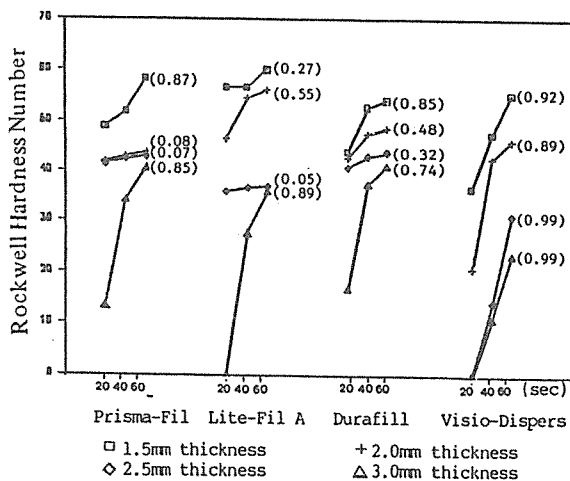


Fig. 7. Rockwell hardness values of composites in relation to the exposure time and specimen thickness. Correlation coefficients are in the parentheses. (Bottom surface)

Table 1. Rockwell hardness values for various exposure time and specimen thickness. Standard deviations are in the parentheses. (n = 5)

Type of Material	sec	Top			Bottom				
		1.5mm	2.0mm	2.5mm	3.0mm	1.5mm	2.0mm	2.5mm	3.0mm
Prisma-Fil	20	49.6 (2.1)	47.2 (4.7)	46.4 (6.8)	18.6 (7.8)	48.6 (2.2)	41.8 (7.8)	42.0 (9.2)	13.2 (7.1)
	40	54.2 (1.3)	48.0 (5.5)	47.6 (6.0)	44.8 (9.5)	51.8 (2.2)	42.8 (12.1)	42.6 (2.9)	34.2 (6.9)
	60	60.2 (1.2)	53.0 (5.8)	51.8 (5.7)	50.2 (6.5)	58.4 (1.9)	43.4 (2.2)	43.4 (10.1)	40.6 (3.2)
Lite-Fil A	20	59.6 (3.4)	50.0 (2.0)	39.6 (2.7)	11.8 (8.1)	56.8 (3.5)	46.4 (9.5)	35.8 (9.7)	* (*)
	40	60.6 (6.5)	57.2 (2.1)	46.6 (4.7)	35.0 (4.3)	56.8 (6.8)	54.6 (3.5)	36.6 (7.7)	27.8 (9.6)
	60	61.2 (2.3)	57.8 (0.7)	55.4 (1.0)	51.0 (6.2)	60.2 (3.2)	56.2 (1.2)	36.8 (3.5)	35.8 (4.0)
Durafill	20	46.2 (1.9)	44.4 (1.0)	40.8 (1.9)	39.8 (1.2)	44.0 (1.1)	42.6 (1.0)	40.4 (1.4)	16.8 (10.7)
	40	53.4 (2.3)	48.2 (0.7)	47.6 (3.4)	44.4 (2.2)	52.8 (2.0)	47.6 (1.0)	43.0 (0.9)	37.4 (5.7)
	60	54.4 (1.4)	53.0 (5.8)	49.4 (1.0)	45.8 (1.9)	54.2 (2.2)	48.6 (7.5)	43.8 (6.0)	41.0 (7.3)
Visio-Dispers	20	45.2 (3.1)	36.3 (4.2)	5.6 (3.0)	* (*)	36.6 (4.0)	20.8 (2.1)	* (*)	* (*)
	40	48.8 (2.7)	47.8 (3.3)	30.0 (6.6)	27.4 (2.7)	47.6 (3.3)	42.6 (4.3)	14.0 (1.1)	11.0 (1.9)
	60	55.6 (5.2)	55.2 (0.7)	36.0 (0.9)	34.2 (1.2)	55.4 (2.1)	46.2 (1.8)	31.2 (1.7)	23.6 (1.5)

* represents that the hardness is lower than the measurable range of Rockwell hardness test

Rockwell hardness values of 1.5mm-thick composite specimens cured for varying exposure time were compared with those of 3.0mm-thick specimens in Fig. 8.

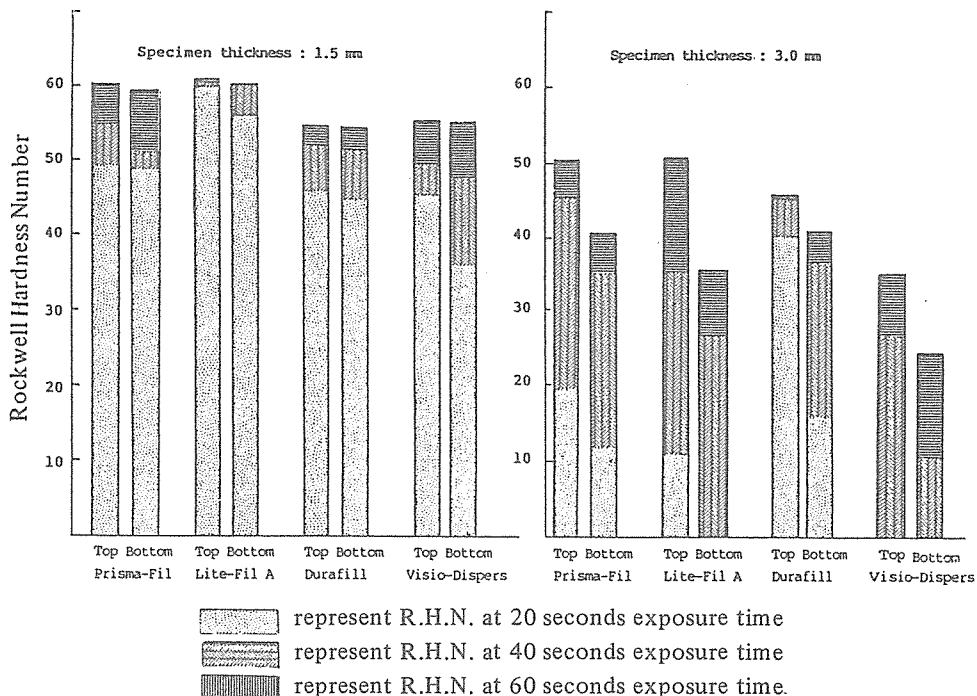


Fig. 8. Histogram illustrating Rockwell hardness values of 1.5- or 3.0mm-thick composite specimens.

The hardness values for each combination of conditions were subjected to two-way analysis of variance.

There was a statistically significant difference in the hardness values between the upper and lower specimen surfaces ($p < 0.001$).

Moreover, in all the four materials, the hardness values significantly differed by the change of the exposure time or specimen thickness ($p < 0.001$).

The magnitude of the hardness reduction by increased specimen thickness varied and was dependent upon the type of resin system.

At 3.0mm specimen thickness and 20 second exposure time, the lower/upper x 100% ratio of hardness was below 50% in all materials except Prisma-fil (Table 2).

This indicates that the degree of polymerization is insufficient in the bottom surface at this condition. There was a tendency that the bottom/top x 100% ratio decreases with the increase of specimen thickness. The hardness decreased even in the top surface by the increase of specimen thickness.

As the exposure time increases, in all specimen thicknesses and in both the top and bottom

Table 2. Bottom/Top x 100% ratio of Rockwell hardness number

(n = 5)

specimen thickness		1.5mm			2.0mm			2.5mm			3.0mm		
exposure time (sec)		20	40	60	20	40	60	20	40	60	20	40	60
Composite Resins	Prisma-Fil	98	96	97	89	89	82	91	89	84	71	76	81
	Lite-Fil A	95	94	98	93	95	97	90	79	66	*	79	70
	Durafill	95	99	100	96	99	92	99	90	89	42	84	90
	Visio-Dispers	81	98	100	57	89	84	*	47	87	*	40	69

surfaces, the hardness values increased. The thicker composite resin specimens showed a more pronounced dependency in this factor (Fig. 8).

In Prisma-Fil and Lite-Fil A the Rockwell hardness values at 1.5mm specimen thickness were higher than those of Durafill and Visio-Dispers in both the top and bottom surfaces. However, as the specimen thickness increases, especially at 3.0mm specimen thickness, the hardness values of the macro-or hybrid- filler type composites were similar to or even lower than that of Durafill. But, the hardness values of agglomerated microfilled composite, Visio-Dispers, were still lower than macro- or hybrid- filler type composites at thick specimens (Fig. 6, 7).

Durafill didn't show a drastic change of hardness in top surface by the change of the specimen thickness from 1.5 to 3.0mm. But, in the bottom surface when the exposure time is only 20 seconds, the hardness decreased drastically (Fig. 7).

As the exposure time increased up to 40 seconds, however, the hardness value in the bottom surface of 3mm- thick specimen approached to those of other specimen thickness.

Like this, Durafill showed a less change in hardness values than other materials by the change of the exposure time or specimen thickness (Fig. 6, 7).

The hardness of the Visio-Dispers was apparently the most sensitive to the changes of specimen thickness as indicated by the considerably lower hardness values at 2.5 and 3.0mm than at the 2.0mm specimen thickness. At 20 second exposure time, when the specimen is thicker than 2.5mm, the lower surface of Visio-Dispers was so soft that the hardness was beyond the measurable range of Rckwell hardness test method.

IV. Discussion

There are several methods for the evaluation of degree of polymerization of dental composite resin. It can be determined by evaluating the amount of residual monomers in polymerized composites^{18,19,20}, or the degree of conversion of double bonds of resin monomer into single bonds in polymerized resin^{21,22,23}, or the exothermic heat changes during the polymerization process.^{24,25}

Moreover, there are some reports that in vitro evaluations of depth of cure are evaluated by hardness measurements.^{23,26)}

Tirtha et al.¹⁾ reported that increased transverse strength was correlated to increased Barcol hardness.

The surface hardness of a composite resin may prove to be related to its wear resistance and ability to maintain form stability. Thus, it would be prudent to measure the surface hardness for the evaluation of the depth of cure.

There would be some possible explanations for this experimental technique.

In the study of Fan et al.⁵⁾, they ascertained that a white, reflective backing promotes the degree of curing on the lower surfaces of the composite resin samples. Thus, this study used polyester matrix strip covered white filter paper beneath the testing mold as a backing to simulate the in vitro situations where white calcium hydroxide bases are used in deep cavities under composite resins.

This probably increased the intensity of light available for photo-activation. In this study, the hardness at the top surface decreased as the specimen thickness increased. It would be explained by the lesser light reflection by the white backing at the thicker specimens.

Another explanation for this experimental technique is that light intensity at the exit window of the light source is less at the peripheral region than at the central zone of the light beam.

This may have been caused by the loss of light energy from the periphery of the beam to the surroundings. Accordingly, we measured the hardness of all the specimens at the central zone.

In the study of Ota et al.¹¹⁾, they found that even though light at exit is uniform, but the intensity of the scattered light from the filler particles is not uniform in the entire section of the region. This light scattering could limit the amount of radiation energy in the bottom surface to activate the photo-initiators for polymerization.

Since fillers will contribute to the light scattering, we are required to retrospect the dental composites to understand the light scattering fillers in resin matrix.

Since Bowen introduced the first composite into dentistry in 1958, many types of composites have been introduced to the profession.

A composite resin generally consists of three phases: matrix phase, inorganic fillers, and bipolar coupling agent which connect the organic resin matrix and the inorganic fillers.

Based on their filler types, four composites are distinguished: traditional composites (TC), hybrid composites (HC), homogeneous microfilled composites (HMC), and inhomogeneous microfilled composites (IMC).

The traditional macrofillers consist of quartz, glass, borosilicate, or ceramic, and are made by grinding and/or crushing large pieces of material into small particles, which are usually splinter-shaped. The size distribution of these ground particles is in the range of from 0.1 to 100 μm . In recent years, with traditional macrofillers, there has been a definite trend toward the use of smaller particles. The average size has shifted from a range of 5 to 30 μm down to 2 to 8 μm .

Prisma-Fil used in this study belongs to this category.

The Homogeneous microfilled composites are made by combining pyrogenic silica into an

organic matrix. Recently, there has been a trend to the use of the average particle size of pyrogenic silica microfiller, about 0.05 to 0.10 μm . It is considered an optimal composite construction as far as surface qualities and wear resistance are concerned. However, the maximum inorganic filler loading with such small particles is still limited because of the huge surface area they present (50-200 m^2 per gram). When only a few per cent by weight of pyrogenic silica is added to the liquid mixture, such a mix becomes extremely viscous and difficult to handle. Thus, homogeneous microfilled composite is still not commercially available.

The hybrid composite consists of small traditional macrofillers, directly admixed pyrogenic microfiller, a coupling agent, and the matrix phase. The pyrogenic silica has been added to reinforce the organic matrix and to reduce the difference in properties between the inorganic macrofillers and the unfilled organic matrix. Lite-Fil A used in this study belongs to this category.

In vivo studies have shown a significantly improved wear resistance compared with traditional composites^{28,29}. But, they suffer the disadvantage of losing their initial luster after a short time in the mouth.

The microfiller-based complexes were developed to obtain a maximum inorganic loading of diacrylate with fumed silica.

Microfilled, prepolymerized complexes can be added without jeopardizing handling properties and viscosity of the mix.

Three different types of microfiller-based complexes can be distinguished: splintered prepolymerized microfilled complexes (SPP), spherical polymer-based microfilled complexes (SphPB), and agglomerated microfiller complexes (AMC).

SPP is the most common type of microfilled composites. It is made by incorporating fumed silica into a resinous matrix. The resulting tough mixture is heat cured and then ground into particles ranging in size from 1 to 200 μm . This prepolymerized, splintered particles are admixed with pyrogenic silica and resin matrix. This composite construction has favorable characteristics (excellent polishability, permanent surface smoothness, and good wear resistance) if properly manufactured. Durafill belongs to this category.

SphPB was developed to overcome some of the disadvantages of SPP. It is manufactured by incorporating pyrogenic silica and spherical prepolymerized particles (suspension polymerized, spheres with an average diameter of 20- 30 μm) into the resin matrix. It permits better packing of resin matrix. The handling properties are good, even when filled to a high volume percentage. Experimental inhomogeneous microfilled composites with spherical prepolymerized particles have shown promising performance. However, such a composite has not yet been marketed.

AMC is similar to macrofillers in size and chemistry, but not in structure. It consists of prepolymerized, agglomerated purely inorganic secondary particles having a particle size of 0.5 - 50 μm and microfillers incorporated into resin matrix. This approach allows an increase in the microfiller content and provides excellent finishing and polishing quality. Visio-Dispers belongs to this category. However, not very much is known about the clinical performance of these restorative resins.^{14,30,31,32}

As we know from above retrospection, there are many different types of composites in the

markets. Thus, it will be helpful for the clinical performance to know the curing depth of each composite type by the variation of curing time and restoration thickness.

Ruyter and Oysaed³³⁾ measured extent of cure in UV and visible light-cured composites using infrared analysis and concluded that the limiting factor for depth of cure in composites was light-scattering. They suggested that the scattering be maximized when the filler particle size was approximately one-half of the wavelength of the activating light.

For this reason, if microfilled resins with smaller and more numerous particles have equal weight percent of filler to conventional composites, they will not cure to as great a depth as conventional composites with larger and fewer glass particles to scatter light. However, we must consider that the amount of the inorganic fillers are also important variable. Fortunately, there are lower filler loading in microfilled resins compared with conventional composites. In experimental reports and advertisements, it is reported that the weight percents of fillers are in Prisma-Fil, 76%; in Lite-Fil A, 84%; and in Durafill, 52%.^{31,32)} The weight percent of fillers in Visio-Dispers is considered to be similar to that of Durafill.

At higher filler loading the light scattering will be more than the lower filler loading composites. Swartz et al.³⁴⁾ reported that the surface hardness of the resin increased as the content and size of the filler increased. This phenomenon, of course, is due to the more resistance of the higher inorganic filler loading composites to the indentation.

In Prisma-Fil and Lite-Fil A the Rockwell hardness values at 1.5mm specimen thickness were higher than those of Durafill and Visio-Dispers in both the top and bottom surfaces. It is considered that this result is due to the higher filler loading at macro- or hybrid type composites (Prisma-Fil and Lite-Fil A) compared with microfiller type composites (Durafill and Visio-Dispers) since more inorganic filler content will increase the surface hardness in case that the light transmission is enough.

However, as the specimen thickness increased, especially at 3.0mm specimen thickness, the hardness values of the macro- or hybrid-filler type composites were similar to or even lower than that of Durafill. This may be due to that at higher filler loadings the light scattering will be more than at the lower filler loading composites.

The hardness values of agglomerated microfilled composite, Visio-Dispers, were still lower than macro- or hybrid- filler type composites at thick specimens. This may be due to the relatively large, more compactly agglomerated inorganic microfiller particles and microfillers appropriate in size to the light scattering.

With this experiment, it would be concluded that the depth of the polymerization depends on the composition, size, and moreover content of the filler in the resin matrix.

In this study, it was found that the bottom surface was softer than the top surface of the specimen. This result shows that a considerable soft unreacted material will be present near the floor of light-activated composite restorations. Thus, it suggests that minimization of this undesirable feature can be accomplished by using a layering technique when placing restorations deeper than 2.5mm for agglomerated microfilled composite resin (Visio-Dispers) and 3mm for other three resins.

As the exposure time increased, the hardness value differences between specimens different in their thicknesses were decreased.

Thus, when the depth of a composite restoration is thick, the other alternative is that we introduce a longer light exposure time.

Although virtually all manufacturers recommend a 20 to 30-second exposure for these resins, the results here seem to indicate that a more than 40-second exposure is more effective with the resins tested. Particularly in deeper cavity preparations.

This data also suggest that in Class III and IV cavities it may be advantageous to cure the restoration from both the facial and lingual surfaces. But it is not possible in Class I, V, and deep class II cavities. In those situations, therefore, it would be prudent to build up restorations in increments or to introduce a longer exposure time.

V. Conclusions

Four different types of visible light-curing composite resins varying in their specimen thickness were evaluated by the Rockwell hardness number obtained immediately after curing for 20, 40, or 60 seconds. As the curing time increased, the hardness of all the four types of visible light cured composite resin increased ($p < 0.001$). The bottom surfaces of composite resins showed a more pronounced dependency on exposure time. The surface hardness of the composite resin decreased as the specimen thickness increased, especially at the bottom surface of the specimen. The hardness of the bottom surface of the visible light-cured composite resin was significantly lower than that of the top surface ($p < 0.001$). The surface hardness of Visio-Dispers was most susceptible to the variation of specimen thickness or curing time, but Durafill showed the most stable hardness values for these variables.

This study shows that when the restoration thickness is thicker than 2.5mm, more than 40-second exposure time is more effective in most composite resins, and as the thickness of visible light-curing composite resin restoration increases, the longer exposure time or curing by layering technique will be required.

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