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Effect of Power Density on Shrinkage of Dental Resin Materials

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Clinical Relevance

Exposure at a lower power density causes less polymerization shrinkage in dental resins and could clinically improve the quality of the bond between the tooth and the restoration.

SUMMARY

This study compares volumetric changes and rates of shrinkage during different stages of polymerization of dental resin composites and compomers exposed to the same total energy by using two different combinations of power density and exposure duration. A hybrid composite and its equivalent flowable and a compomer and its equivalent flowable were exposed using a halogen curing unit set at 400 mW/cm² for 40 seconds and 800 mW/cm² for 20 seconds: delivering 16 J/cm² in both cases. Volumetric changes were recorded every 0.5 seconds using a mercury dilatometer. Ten replications per test condition were performed and the data were subjected to ANOVA. Statistically significant differences in shrinkage values and rates among different power densities were determined by means of

paired *t*-tests at a 95% confidence level. Significantly more shrinkage ($p<0.05$) was found for the higher filled materials, Z250 and Dyract AP, when higher power density was used. However, no significant differences were found between their flowable counterparts when exposed to various power densities. Of the four materials, only Dyract AP exhibited no significant difference in shrinkage rate when various power densities were used. All the other materials exhibited significantly higher rates ($p<0.05$) at the higher power density.

INTRODUCTION

Light-curing dental materials that adhere to tooth structure have revolutionized modern restorative dentistry. However, perfect adaptation should be obtained during the setting reaction of a material. Unfortunately, materials such as resin composites and compomers do not meet this requirement. The primary problem is that the polymerization reaction of the matrix phase causes dimensional instability of the restorative material. The conversion of monomer molecules into a polymer network is accompanied with closer packing of the molecules, which leads to bulk contraction (Koran & Kurschner, 1998). As most composites and compomers contain camphorquinone as the photo-initiator, a substantial power density of approximately 470-nm wavelength is required for complete polymerization (Miyazaki, Fukuishi & Onose, 1999). The optimal duration of light exposure and intensity for resin composites and compomers are, as yet, unknown.

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Studies (Feilzer & others, 1995; Miyazaki & others, 1999) have reported that marginal adaptation is more effectively preserved when the polymerization process is slower. These studies assert that slower polymerization causes an improved flow of molecules in the material, which is associated with less shrinkage. However, it must be taken into account that complete polymerization is important in order to obtain sufficient surface hardness, which is accomplished only by means of a satisfactory period of high intensity illumination (Feilzer & others, 1995; Lovell, Newman & Bowman, 1999; Althoff & Hartung, 2000). Photo-energy radiated from the curing light is directly equal to the intensity and the period of radiation. Althoff and Hartung (2000) reported that in order to reduce the exposure time by half, the intensity of the curing light had to be doubled. Therefore, lengthening the exposure period or increasing the intensity results in increased energy density, increased degree of conversion and, unfortunately, more volumetric shrinkage. This could give rise to increased tension on the bond (Miyazaki & others, 1999). Uno and Asmussen (1991) recommend that low intensity light be used in order to bring about lower polymerization speed, thus, counteracting the tension, which is compensated for by a longer exposure duration.

For the sake of convenience and for economic reasons, it is in the best interest of a practicing dentist to minimize the clinical exposure time of resin-type restorations. Over the past few years, the industry has focused on reducing the resin exposure time by using stronger curing lights and/or altering resin composition and photoinitiator concentration (Rueggeberg, Ergle & Lockwood, 1997). The impact these new devices and new composite formulations have, however, are complex and not yet fully understood. Recently, a number of manufacturers have introduced light-curing units capable of pro-

ducing various levels of power density and variable modes of application.

This study compared polymerization shrinkage in dental composites and compomers using different power densities but with the same energy density. The research hypothesis was that if the power density was doubled but the same total energy levels maintained, the rates of cure and the total shrinkage at various times would not increase for any material tested.

METHODS AND MATERIALS

Four light curing materials were tested, comprising two resin composites (color A3) and two flowable composites (color A3) (from the same companies) (Table 1). Ten readings for each of the materials were taken with the light source set at 400 mW/cm² for 40 seconds and 800mW/cm² for 20 seconds, respectively, at a temperature of 25°C ±10. The light source for this experiment was a Spectrum 800 (Dentsply/Caulk, Milford, DE, USA). The power density of the light source was veri-

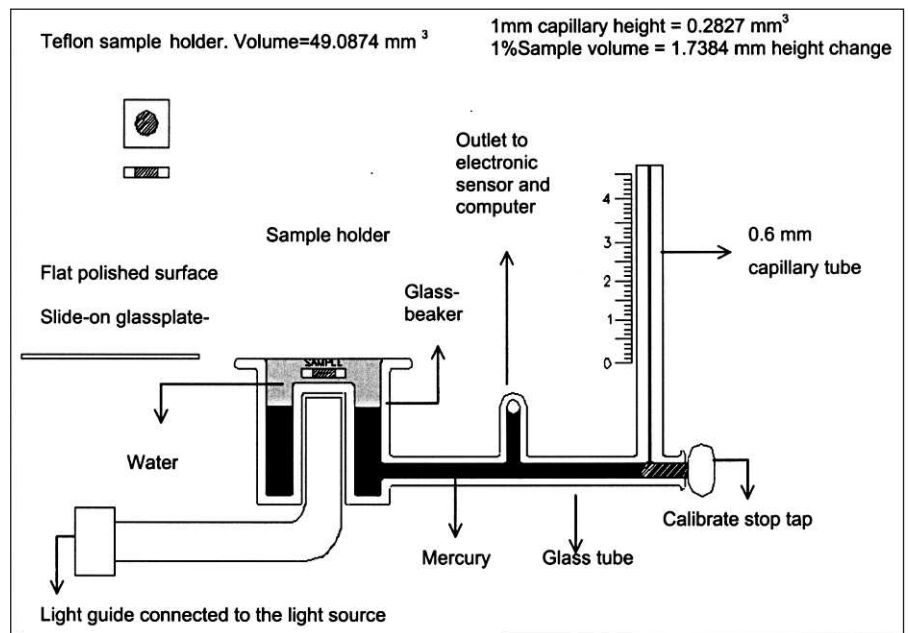


Figure 1. Schematic image of the glass parts of the dilatometer and the teflon sample holder (top left).

Table 1: Materials Tested and Their Filler Composition as Supplied by the Manufacturers

Material	Manufacturer	Batch # (Expiration Date)	Filler Particle Size	Filler Content/Weight	Filler Content/Volume
Z-250 (Composite)	3M Dental Products, St Paul, MN, USA	20000717 (2003-04)	0.6 µm	80%	60%
Filtec-flow (flowable composite)	3M Dental Products, St Paul, MN, USA	20000417 (2003-04)	1.5 µm	68%	47%
Dyract AP (compomer)	Dentsply/Caulk, Milford, DE, USA	0101001343 (2003-01)	0.8 µm	73%	49%
Dyract-flow (flowable compomer)	Dentsply/Caulk, Milford, DE, USA	0101001077 (2002-07)	1.6 µm	60%	38%

fied using a hand-held dental curing radiometer (Dentsply/Caulk).

Volumetric changes were determined by a dilatometer with an average coefficient of variation of less than 1.22% as described by Oberholzer and others (2002). Any change in volume of the sample resulted either in expansion or contraction, which is registered as a change of the liquid height in the capillary. A diagram of this system is shown in Figure 1.

Instead of manually viewing and recording the liquid height, the column pressure was measured electronically with a pressure sensitive transducer and recorded by a computer that also stored the data. The relationship between shrinkage and the pressure transducer output had been correlated and calibrated (Oberholzer & others, 2002). The computer also recorded the temperature and controlled the light source. Since it is important that dilatometers operate at a constant temperature, the apparatus was placed in an incubator that maintained a temperature of 25°C ±10 while readings were taken.

The samples were randomly selected and a standard procedure followed for each specimen. A thin layer of silicon grease was applied to the edge of the glass beaker, which was filled to the brim with distilled water. The sample to be tested was prepared by placing the Teflon specimen holder on a lubricated glass cover slip, completely filling the hole with the material, using a resin disposing gun and scraping the excess off with a glass plate (volume=49.087 mm³, thickness=2 mm). The specimen holder was then placed on the platform of the glass beaker with the open end facing upward and away from the curing light. The glass cover plate was

placed on the beaker and checked to make sure that it was properly sealed and that no air was trapped. A clamp was placed on the cover plate to ensure that it would remain properly sealed. The height of the column of mercury in the capillary tube and the computer was adjusted until both had a “0” reading. The computer was then activated to register a reading that was monitored for five seconds. If the computer found the system unstable, it would reject the test and request that the container be sealed again. Once the system was stable, the computer activated the light curing apparatus for 20 or 40 seconds, respectively, at the chosen intensity and readings were taken at half-second intervals.

The data were tabulated and the mean and the standard deviation were calculated. Shrinkage rates for the four materials were compared using ANOVA at a pre-set alpha of 0.05. Statistically significant differences between different power densities were determined by means of paired *t*-tests at a 95% confidence level (*p*<0.05). For each recording of a specific material, the following parameters were established: (i) the mean values for the slope (%/time) of the shrinkage curves (rates), (ii) the mean value of shrinkage after an exposure period of 20 and 40 seconds measured at 40 seconds (iii) and

Table 2: Rates of Polymerization Shrinkage (%/time) Using Different Power Densities

Material	Power Density mW/cm ²	Mean Values(%/time) (sd)	p=
Z 250	400	0.162 (0.010)	0.008
	800	0.206 (0.022)	
Filtec Flow	400	0.124 (0.024)	0.000
	800	0.185 (0.017)	
Dyract AP	400	0.119 (0.022)	0.527
	800	0.127 (0.024)	
Dyract Flow	400	0.161 (0.032)	0.017
	800	0.203 (0.025)	

N=10 specimens per test condition
Vertical lines indicate statistically different values (*p*<0.05)

Table 3: Volumetric Shrinkage of Restorative Materials at 35- and 55-Seconds After Light Exposure Was Initiated

Material	Power Density (mW/cm ²)	Mean Values(%) at 35 Seconds (sd)	p=	Mean Values (%) at 55 Seconds (sd)	p=
Z 250	400	0.991 (0.071)	0.004	1.011 (0.088)	0.009
	800	1.304 (0.108)		1.317 (0.104)	
Filtec Flow	400	2.305 (0.112)	0.425	2.463 (0.137)	0.695
	800	2.385 (0.193)		2.505 (0.204)	
Dyract AP	400	1.183 (0.096)	0.001	1.303 (0.1110)	0.003
	800	1.541 (0.114)		1.652 (0.147)	
Dyract Flow	400	3.326 (0.120)	0.892	3.417 (0.141)	0.528
	800	3.318 (0.087)		3.469 (0.132)	

N=10 specimens per test condition
Vertical lines indicate statistically different values (*p*<0.05)

the mean value of shrinkage measured after 60 seconds of measurement.

RESULTS

Table 2 shows the values for the rates of shrinkage obtained during polymerization of the four materials when exposed at a power density of 400 mW/cm² for 40 seconds and 800 mW/cm² for 20 seconds. It was found that only the compomer (Dyract AP) showed no significant difference in the rate of shrinkage with respect to power density ($p < 0.05$). All the other materials showed a significantly higher shrinkage rate with increased power density.

Descriptive statistics of polymerization shrinkage of the four materials tested after 40 and 60 seconds, respectively, are shown in Table 3. Generally, more polymerization shrinkage was demonstrated when a higher power density was applied. After 40 and 60 seconds, significant differences in shrinkage were shown for the higher filled materials (Z250 and Dyract AP) when higher power densities were used ($p < 0.05$). However, no significant differences were found for the two flowables.

Graphic illustrations of the volumetric changes that took place in the different materials when exposed at various power densities are shown in Figures 2-5. The contraction rate as shown by the gradients of all the curves is at its highest during the first 20 seconds of exposure. With the composite (Figure 2), the polymerization process was nearly completed after 20 seconds of exposure with both power densities, while shrinkage could still be demonstrated in the other materials (Figures 3-5) even after approximately 40 seconds.

DISCUSSION

Yap and Seneviratne (2001) performed studies on the influence of light energy density on the effectiveness of composite cure. They found that optimal cure at the bottom surface of a 2-mm deep Z100 restoration could be achieved using a 20 second exposure at 600 mW/cm² and 40 seconds at 400 mW/cm². Based on these findings, it was assumed that in this experiment the degree of conversion

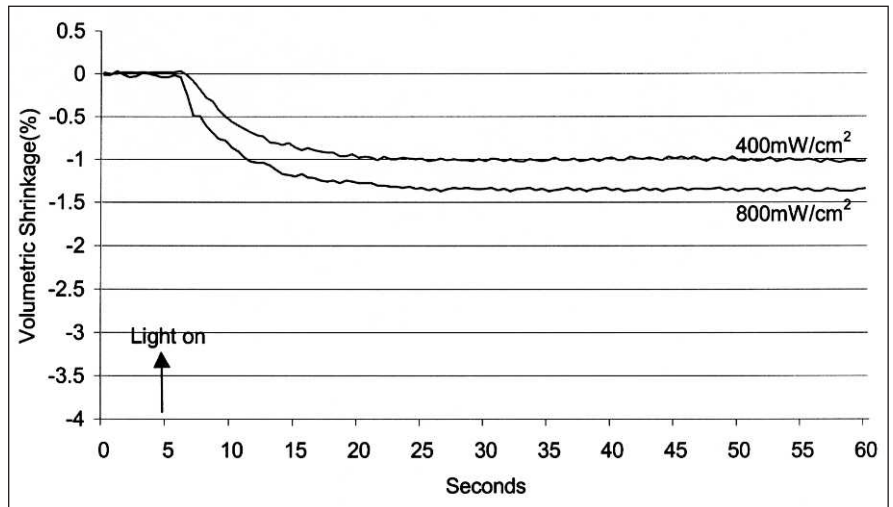


Figure 2. Polymerization shrinkage curves for Z 250 exposed at different power densities.

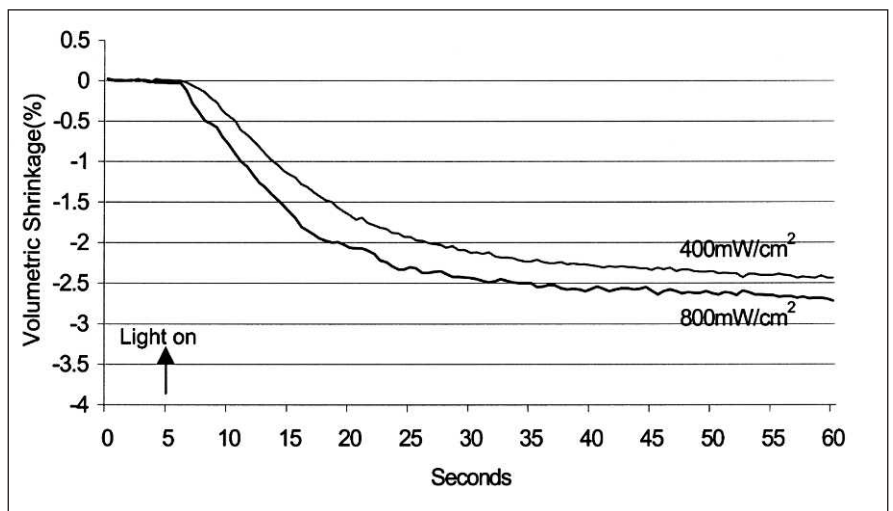


Figure 3. Polymerization shrinkage curves for Filtec Flow exposed at different power densities.

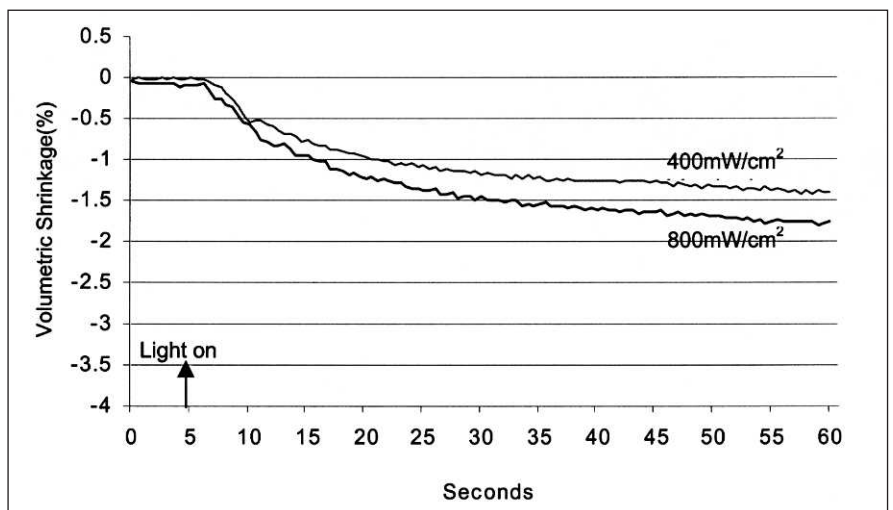


Figure 4. Polymerization shrinkage curves for Dyract AP exposed at different power densities.

should be adequate and equivalent for both power densities (16 Joules).

The results obtained showed that after 40 and 60 seconds, the two higher filled materials, Z250 and Dyract AP, shrink significantly more ($p < 0.05$) when exposed at 800 mW/cm^2 than at 400 mW/cm^2 . For these materials the research hypothesis was thus rejected. This corresponds with the findings of other authors, including Uno and Asmussen (1991); Koran and Kurschner, (1998); Silikas, Eliades and Watts (2000); Miyazaki and others (1999). A contributing factor in the amount of polymerization shrinkage that occurs is the number of monomers per volume of a resin material (Venhoven, de Gee & Davidson, 1993). Thus, to reduce polymerization shrinkage, the number of polymerizable monomers at a certain stage should be reduced. According to Ferracane and others (1997) and Lovell and others (2001), exposure at lower power densities may lead to this. However, it must be kept in mind that a high monomer conversion remains important for optimal physical characteristics and that the intensity of the curing light cannot be reduced indefinitely (Rueggeberg, Caughman & Curtis Jr, 1994). Rueggeberg and others (1994) found that a longer exposure time could compensate for a lower intensity in terms of monomer conversion. However, they found that using a curing light with an intensity of more than 578 mW/cm^2 and an exposure time of more than 60 seconds had no significant advantages.

Conversely, the different power densities had no significant effect on the amount of shrinkage found for the two "flowable" materials, Dyract Flow and Filtec Flow (Tables 3 and 4). For these materials, the research hypothesis was thereby sustained. A probable explanation for the difference is that shrinkage of a material with a higher monomer concentration during polymerization will be enhanced by the lower filler contents as less light attenuation occurs when the filler particles are reduced (Ferracane & Greener, 1986). The photosensitizer concentrations in the matrix phase may also have an effect on the responsiveness to particular power densities. Rueggeberg and others (1997) and Silikas and others (2000) found that the higher the photosensitizer concentrations, the more rapid the polymerization. Furthermore, the ratio between the particle size and filler content is different for the "flowable" materials on the one side compared to the others.

The three-dimensional molecular structures of the monomers in a material might also play a role. For example, Z-250 and Dyract AP also contain UDMA, where the urethane part can be a large molecule and may be extended with an aliphatic or even an aromatic

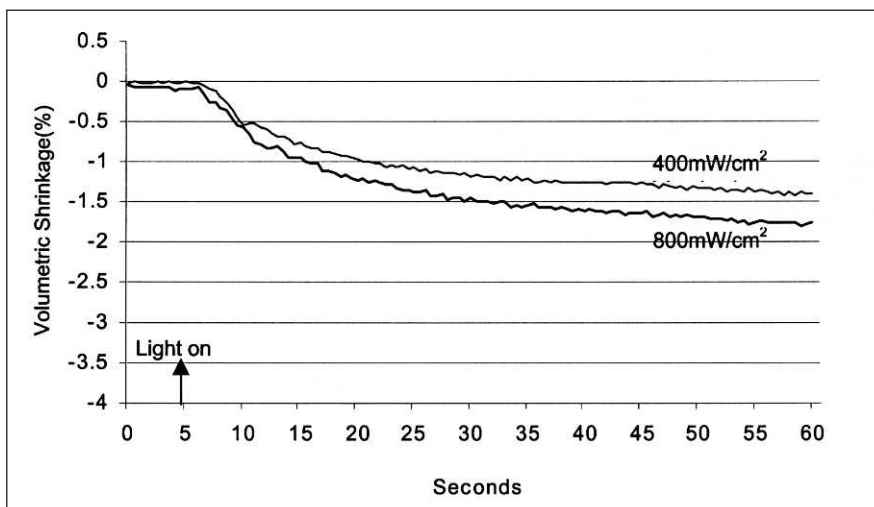


Figure 5. Polymerization shrinkage curves for Dyract Flow exposed at different power densities.

group. It is therefore possible that in this experiment the polymerization process of the flowable materials was already nearly completed at the lower power density, and that applying a higher power density could not induce more polymerization. This was probably not the case with the higher filled materials, where a higher power density caused more polymerization shrinkage. This finding coincides with those of Goldman (1983); Davidson and Feilzer (1997) and Rees, O'Dougherty and Pullen (1999), that the addition of monomers causes polymerization shrinkage to increase, while increasing filler content generally causes less polymerization shrinkage. Thus far, it has been generally accepted that this is applicable to all resins. The results of this study, however, show that a difference in shrinkage is demonstrated when the influence of high and low power densities on materials and their flowable counterparts is compared.

Although the total energy remained the same, it was found that contraction rates were generally higher when exposed at a power density of 800 mW/cm^2 compared to 400 mW/cm^2 (Figures 2-5). Therefore, in this case, the research hypothesis for contraction rates was rejected. This result corresponds with the findings of Sakaguchi, Douglas and Peters (1992), Bouschlicher, Vargas and Boyer (1997) and Dennison and others (2000).

Sakaguchi and others (1992) demonstrated a linear relationship between power density and polymerization shrinkage. They found that the higher the power density of the curing light, the sooner polymerization takes place and the greater the contraction rates. Clinically, this finding is of great importance, as the bond between the tooth structure and the restoration can be compromised at this early stage, possibly causing microleakage. A further disadvantage of high intensity exposure is that quicker termination of the polymerization process may occur due to the enhanced formation of certain ter-

minating radicals. This may lead to further tension within the restoration (Althoff & Hartung, 2000). Rapid polymerization also generates reactive heat within the material, thus, enhancing the polymerization process. This process, known as the "Trommsdorff effect," causes a vast increase in the viscosity of the material (Goracci, Mori & de' Martinis, 1996).

CONCLUSIONS

This work is based on a study of four commercially available, well-researched materials. It is probable that the conclusions will also apply to a wider range of materials with comparable formulations. Within the conditions and limitations of this study, the following conclusions may be drawn:

1. Higher filled materials show more polymerization shrinkage when exposed to the same total energy but at higher power densities, while this finding is less significant for "flowable" materials.
2. Exposure to the same total energy, but using a lower power density, causes less and slower rates of shrinkage in the dental resins tested.

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