

# Influence of Polymerization Light Intensity on the Polymerization Shrinkage of Composite Materials (Part III)

Alena Knežević<sup>1</sup>  
Nazif Demoli<sup>2</sup>  
Zrinka Tarle<sup>1</sup>  
Višnja Negovetić Mandić<sup>1</sup>

<sup>1</sup>Department of Restorative Dentistry School of Dental Medicine University of Zagreb  
<sup>2</sup>Institute of Physics, Zagreb, Croatia

---

## Summary

*Composite materials shrink during the polymerization process which lessens their clinical value. Modifications of composition of the composite material and application technique proved inadequate for compensation of polymerization shrinkage, and therefore modification of polymerization modes was attempted. The polymerization modes of lower intensities will enable prolongation of the pre-gelation phase and consequently greatly decrease the total amount of shrinkage. The purpose of the study was to determine the polymerization shrinkage of Tetric Ceram (Vivadent, Schaan, Liechtenstein) and Filtek Z 250 (3M/ESPE Dental Products, St Paul, MN) composite materials by digital holographic interferometry. Samples of the composite material were polymerized by three modes of various intensities (medium, exponential and standard) Elipar Trilight halogen curing unit (3M/ESPE, Seefeld, Germany). Highest values of the polymerization shrinkage were recorded for the polymerization mode with highest light intensity.*

**Key words:** *composite materials, polymerization shrinkage, digital holographic interferometry, halogen curing unit.*

---

Acta Stomat Croat  
2005; 461-464

ORIGINAL SCIENTIFIC  
PAPER  
Received: May 10, 2005

Address for correspondence:

Alena Knežević  
Department of Restorative  
Dentistry  
School of Dental Medicine  
Gundulićeva 5, 10000 Zagreb  
Croatia  
Phone: ++385 (0)1 48 02 113  
Fax: ++385 (0)1 48 02 159  
e-mail: ma505ak@yahoo.com

---

## Introduction

Despite daily perfecting both the composite material and light sources, the polymerization shrinkage of composite materials still remains a significant problem that compromises longevity of composite fillings. On average, the composite materials shrink 1-5% volume (1). Total shrinkage can be divided into pre- and post- gelation phase. During the pre-gelation phase, the composite material is not completely set and monomers have the possibility of rearrangement within the forming polymer matrix.

During the post-gelation phase monomers loose that ability, which results in the occurrence of stress on surrounding cavity walls and on the bond between the tooth and composite material (2). As a consequence of stress, defects can form inside the bond between the tooth structure and the composite material, breakage and formation of microcracks that further causes postoperative sensitivity and recurrent caries.

There are several ways of compensating the negative effect of polymerization shrinkage, including placement of liner, layered placement of compos-

ite material, modification of the composition of the composite material, and today more often by using light sources with lower initial intensity to enable "flow" of material during the pre-gelation phase of the polymerization process (3).

Several different procedures have been described in recent literature for measuring polymerization shrinkage. Direct methods, such as dilatometric method (mercury or water dilatometer), linometer, measuring difference in the specific weight and density of the material and "strain-giage" method encompass the measurement of dimensional changes of the material created during setting. Indirect methods are based on determining the depth of bacterial infiltration, air pressure, electromechanical methods, radio isotopes, liquid penetration, and electron microscopy, thermal and mechanical cycling (4). The latest direct method for measuring polymerization shrinkage, digital laser interferometry, used in this experiment, is the only method that enables detection of changes and calculation of total shrinkage of the composite material for every second of the polymerization (5, 6, and 7).

The purpose of this study was to examine the influence of halogen curing unit with polymerization modes of different intensities on polymerization shrinkage of two composite materials.

### Materials and methods

For this experiment composite materials Tetric Ceram (TC) (color A1) (number B49177) and Filtek Z 250 (F) (color A1) (number 20000222) were used. Composite material samples were polymerized with Elipar Trilight halogen polymerization device with three polymerization modes of different intensities:

1. "Medium mode" (ETM)
2. "Exponential mode" (ETE)
3. "Standard mode" (ETS)

ETM and ETS modes emit uniform intensity light of 450 mW/cm<sup>2</sup> (ETM) and 800 mW/cm<sup>2</sup> (ETS). During illumination by ETE mode illumination starts with intensity of 100 mW/cm<sup>2</sup> and gradually rises for 15 seconds to 800 mW/cm<sup>2</sup> where it remains for the remainder of 40 seconds. The con-

trol group consisted of samples polymerized by ETE polymerization mode.

For measuring polymerization shrinkage samples were made 0.65 mm thick. Each sample was placed between two celluloid foils, each 0.75 mm thick. The sample prepared in this fashion was placed in an inox ring 1 mm thick and diameter 1 cm and pressed between two round inox plates to 1 mm thickness and diameter 2 cm so that total sample and foil thickness equaled 1 mm.

A total of 60 samples were made: 30 for TC and 30 for F composite material. Each 30 samples of material were divided in three groups: 10 samples were polymerized with ETM mode, 10 with ETE mode and 10 with ETS mode.

Each sample was placed on a glass plate lying on the movable part of the sample carrier above the opening for sample polymerization. A glass plate whose surface was steamed with an aluminum layer (mirror) was placed on the sample (covered with foil) to serve as a pointer for the laser beam.

The laser beam was split into two parts by a diverter. One part reflects on the wedge shaped diverter and falls directly on the CCD camera, while the other part falls on the sample carrier mirror. The scheme of the optical device is presented in Figure 1. It enables the beam of blue light (468nm) to polymerize the sample from the bottom side and at the same time measures shrinkage or stretching of the sample using a red laser light (633 nm).

Therefore, two laser light beams merge, one coming from the mirror placed on the sample surface and other coming from the fixed mirror. The CCD camera records the created interference image and it is further analyzed by a personal computer. The computer program enables interference stripes analysis and their conversion in numerical values of the polymerization shrinkage. TC composite material was polymerized, according to the manufacturer's recommendations for 40 and F for 20 seconds. In the case of the F composite material the recording was continued for the following 20 seconds to determine whether there was any difference in the polymerization shrinkage values after the end of illumination.

Results obtained by the polymerization shrinkage measurements were statistically analyzed using student descriptive statistics, variance analysis for difference in shrinkage considering the light source

and t-test for independent variables to determine whether there is difference in polymerization shrinkage with regard to the composite material. Results are shown in Tables 1-3. Example of polymerization shrinkage as a direct presentation of measurements for a single sample was represented graphically for each second of illumination.

## Results

During data analysis shrinkage was observed in relation to the polymerization mode individually for the materials F and TC, using descriptive statistics and analysis of variance (Tables 1 and 2).

When F material was used statistical difference for shrinkage was found ( $p < 0.05$ ) in relation to the polymerization mode after 20 seconds (end of polymerization). After 20 seconds no difference was found between ETE and ETS ( $p > 0.05$ ), while it was found between others ( $p < 0.05$ ). Greatest shrinkage was found when ETS mode was used and least when ETM mode was used for both polymerization times.

When TC material was used, difference in shrinkage in relation to the polymerization mode after 10, 20 and 40 seconds between all three polymerization modes ( $p < 0.05$ ). After 10 seconds expansion was noticed for ETE mode, while for ETM mode shrinkage was less than for ETS.

After 20 seconds the smallest shrinkage was found for ETM and greatest for ETS, while after 40 seconds the smallest shrinkage was found for ETM and greatest for ETE.

This study also observed differences in shrinkage in relation to the material (F:TC) using t test for independent variables at the 10th second and at the end of polymerization (40th second for TC, 20th for F).

In the case of ETM polymerization mode statistically significant difference was found between the two materials used only at the end of polymerization ( $p < 0.05$ ), while at the 10th second there was no difference ( $p > 0.05$ ). Greater shrinkage at the end of polymerization was found for F material.

ETE polymerization mode exhibited difference in shrinkage between the two materials used

for the 10th second and at the end of polymerization ( $p < 0.05$ ). At the 10th second TC showed initial expansion and had greater shrinkage at the end of polymerization.

ETS polymerization mode showed difference in shrinkage between the two materials at the 10th second and at the end of polymerization ( $p < 0.05$ ). F material showed greater shrinkage at the 10th second and TC at the end of polymerization.

Figures 2 and 3 represent polymerization shrinkage for every second of illumination. Initial expansion of the samples was observed when using ETE mode (deviation of the curve in negative direction). Figures show that the highest polymerization shrinkage occurs around the 20th second of illumination.

## Discussion

Composite material polymerization is essentially connected with shrinkage because of the short covalent bond formation between the monomers. Different attempts were made to compensate the problem of shrinkage, one of the more significant being initial polymerization with a lower intensity polymerization device.

Exposure of the composite material to lower light source intensity can result in more difficult photo initiator activation, especially in deeper parts of the filling. On the other hand, faster polymerization at high polymerization intensity, despite higher degree of conversion, results in shorter and more cross connected polymers because initial reaction is too fast, which leads to faster polymerization termination (8, 9). Uno and Asmussen (10) and Sakaguchi and Berge (11) recommend use of low intensity light for polymerization to enable gradual setting of the material which lessens stress formation during shrinkage and microcracks as a consequence.

Figures 2 and 3 show initial expansion at both ETM and ETS polymerization modes which last significantly shorter than 10 seconds and therefore are not visible in the tables. Figures clearly show that the light intensity effects polymerization shrinkage and that ETE mode results in lowest polymerization shrinkage for the first 15 seconds when it emits lowest intensity light ( $100 \text{ mW/cm}^2$ ). After that interval, with increase in the light intensity ( $800 \text{ mW/}$

cm<sup>2</sup>) polymerization shrinkage increases and surpasses the polymerization shrinkage values obtained by ETM mode (450 mW/cm<sup>2</sup>).

Interestingly, the polymerization shrinkage curve for F composite material has a similar shape to the curve for TC material polymerized for 40 seconds, regardless of the fact that illumination stops after 20 seconds. Explanation lies in the composition of the composite materials: amounts of TEGDMA, UDMA, BisGMA, and EGDMA. F contains BisGMA, BisEMA and UDMA. Increase of UDMA decreases module of elasticity, and lower elasticity module enables greater flow of the material as well as plastic deformation (12). Furthermore, the amount of TEGDMA influences the polymerization in the post radiation period in such a way that higher ratio of TEGDMA decreases polymerization in the post radiation period (12). According to the manufacturers, F does not contain TEGDMA which can also be one of the factors for continuation of polymerization shrinkage in the post radiation period, similar to polymerization shrinkage for TC composite materials.

Results of polymerization shrinkage obtained in this study correlate with the results for polymerization shrinkage obtained by other authors: Meiers et al. measured values for linear polymerization shrinkage ranging from 0.8 to 1% (13), Feilzer et al. (14), and deGee et al. (15) shrinkage measured in this experiment using holographic interferometry ranging from 0.12 to 0.98% of the linear shrinkage.

Composite materials with a high portion of filler are susceptible to smaller polymerization shrinkage while smaller filler ratio means higher ratio of organic matrix. Since glass particles are not susceptible to shrinkage, organic matrix is responsible for shrinkage because of the formation of bonds and deformations due to the change from gel to sol state.

A second factor connected with shrinkage is the size of the filler particles. Larger filler particles cause greater shrinkage of the material. Accordingly, composite materials with smaller filler particles will shrink less. Increase in size of the inorganic filler particles cause a higher amount of organic

matrix between the particles. Smaller particles have smaller distance between them and consequently, a smaller amount of organic matrix inbetween. In contrast, smaller particles cause greater dispersion of light and worse polymerization. The larger particles enable better transmission of light and greater degree of conversion, but also greater polymerization shrinkage (10).

An unavoidable consequence of composite material polymerization is the formation of stress in the material, surrounding tooth structures or on the connecting surface between the tooth and the material. The most interesting compensation possibility for the stress caused by polymerization shrinkage, besides the placing of so-called "liners", flowable composites and layering technique, would be the use of "soft-start" mode with lower initial intensity such as ETE polymerization mode. This type of light illumination attempts to avoid rapid initial polymerization followed by high temperature rise and consequently further increase in the polymerization process ending in gel effect or Trommsdorf effect, or in other words, rapid increase in the viscosity of the material (16, 17). Purpose of the gradual polymerization is prolongation of the pre gelation phase, when shrinkage can be compensated, and shortening of the post-gelation phase when tension forms between the material and the surrounding tooth structures. For better polymerization and less polymerization shrinkage in deeper layers of the composite materials it is recommended that the setting time is prolonged with lower intensity rather than accelerate the polymerization with higher polymerization device intensity (17, 18).

## Conclusion

Many factors cause polymerization shrinkage of composite materials and may lead to microfractures and microgaps and consequently pulp tissue injury. According to the results of this study, such a negative consequence could be avoided by using a curing unit with initial lower light intensity for photopolymerization of composite resins.