

Effect of Shade on Immediate and Post-Curing Polymerization Shrinkage of Composite Resin

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Abstract

Background and Aim: Minimizing the polymerization shrinkage of composite resins is a critical goal in composite restorations. Many factors affect polymerization shrinkage. This study aimed to evaluate the effect of composite resin shade on its polymerization shrinkage.

Materials and Methods: In this in vitro study, 14 composite discs measuring 1.5×8 mm were fabricated from the A2 and WB shades of G-aenial composite resin. Composite resin discs were placed in a brass ring bonded to a glass slide. Another glass slide was placed over it. The samples were light-cured at 750 mW/cm² light intensity for 20 seconds. Polymerization shrinkage and its strain rate were measured for up to 600 seconds after the onset of irradiation by the bonded disc technique and a linear variable differential transformer machine. Data were analyzed by independent-sample t-test ($P\leq 0.05$).

Results: The polymerization shrinkage strain at 20 and 600 seconds was not significantly different between the WB and A2 shades of G-aenial composite resin. The differences in polymerization shrinkage in each group at 20 and 600 seconds were significant ($P<0.000$). The difference in the shrinkage rate between the two groups up to 20 seconds was not significant ($P=0.505$).

Conclusion: The polymerization shrinkage of G-aenial composite resin was not affected by shade. However, in both shades, polymerization shrinkage showed a significant difference immediately after irradiation and 600 seconds after that.

Key Words: Composite Resins; Polymerization; Color

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Introduction

Due to the growing importance of esthetics in dentistry and the interest of patients and dentists in more conservative procedures, composite resins have been more commonly used in the recent years (1). The main advantage of composite resin restorations is their esthetic characteristics and color matching with the adjacent teeth. Different shades of

composite resins with varying lumenencies are available to better match the tooth structure and improve the esthetic appearance of restorations (2).

Failure of composite resin restorations has been reported to be as high as 40%, with esthetic problems as one of the factors responsible for such failures (3). Composite resins' polymerization occurs by the conversion of

matrix monomer molecules to polymer chains, decreasing the space between them. Therefore, the overall volume of composite resin decreases compared to the initial volume, known as polymerization shrinkage. Excessive polymerization shrinkage leads to restoration failure (4, 5). Polymerization shrinkage is one of the fundamental issues in evaluating the composite resins. The degree of conversion of composite resins is usually 55–75%; the polymerization shrinkage of composite resins increases at higher degrees of conversion (6). This shrinkage creates stress between the tooth and composite resin. It creates small gaps between the tooth and composite resin, which lead to salivary microleakage, bacterial penetration, and recurrent caries, eventually resulting in restoration failure. The rate of shrinkage depends on various factors, including the curing time, the light-curing unit's radiation intensity, composition of the matrix, filler content, concentration of photo-initiator in the composite resin, thickness of composite resin increments, optical properties of composite resin, and fillers and pigments used in the composite resin (7, 8). Currently, most composite materials available in the market are activated by photo-initiators, and the dentist has complete control over the working time (7, 9). The manufacturers have incorporated different pigments into the structure of composite resins to improve their color match with the natural teeth. The available color shades range from the opaque shade to cover discolorations to very bright shades to veneer bleached teeth, which are expected to affect light transmission through composite resins (7). Shortall et al. evaluated the effect of different shades of composite resins and their opacities on the degree of conversion (10). They evaluated five different compositions of hybrid composite resin and one single model of composite resin (Pertac-Hybrid, Prisma AP.H, Brilliant, Charisma, Herculite) and Z100 (three shades), Vita A2 and A3.5 and C2 (two opacities) for the enamel and dentin. They reported significant differences between composite resins with the same shade, which might be attributed to filler structure, size, and

loading differences. In addition, it has been reported that the Vita shade shows different colors and shades in different composite resin products, which might explain the differences in the degree of conversion among various campsite resins with the same Vita shade (10). The polymerization shrinkage is different in products of different manufacturers. Different shades exhibit different polymerization shrinkage rates; darker shades are cured at shallower depths than lighter ones (10).

The polymerization process begins immediately after light irradiation. The first polymerization step is the gel stage, which is referred to as the gel point. Before this point, the composite resin is like a dense material that can release the tensions (pre-gel state). After this point, the composite resin is converted to a hard material without flow (4). The polymerization process continues for 24 hours after light irradiation (post-curing), and maximum polymerization occurs a few minutes after the initiation of polymerization (11). It has been reported that lower initial polymerization of composite resin is associated with greater post-polymerization (11).

One method to evaluate polymerization shrinkage is the disc method, including bonded disc method introduced by Watts and Cash (13) and the non-bonded disc method introduced by Feilzer et al (14). According to Watts and Cash (13) and Feilzer et al, (14) since the composite resin is bonded from all the aspects in the bonded disc method, dimensional changes can take place only in one direction, and the rate of linear polymerization shrinkage is almost equal to the volumetric polymerization shrinkage (13, 14).

The polymerization measurement technique is widely used as a reliable method to determine the degree of conversion. Therefore, this study aimed to evaluate the effect of shade on immediate and post-curing polymerization shrinkage of two anterior and posterior composite resins. The null hypothesis was that no significant difference would be found in polymerization shrinkage of different shades of composite resins.

Materials and Methods

In this in vitro study, the samples consisted of 14 G-aenial composite resin (GC Corporation, Tokyo, Japan) discs measuring 1.5×8 mm. The sample size was calculated using Med Calc software assuming $\beta=0.1$ and $\alpha=0.05$; seven specimens were included in each group (15). The samples required 5-6 times of scanning before and after curing (i.e., polymerization) to carry out the measurements.

The bonded disc technique was used to determine the shrinkage strain at $23 \pm 1^\circ\text{C}$. The bonded disc technique was introduced by Watts and Marouf in 2000 to assess the shrinkage strain (Figure 1) (16).

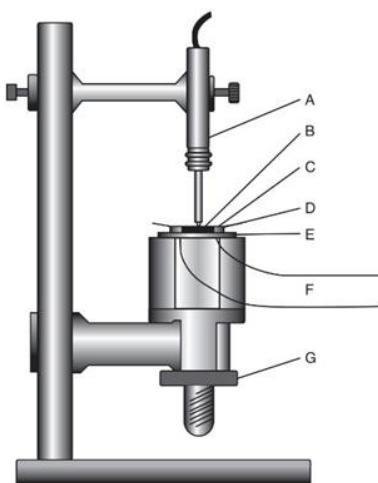


Figure 1. A schematic view of the cross-section of the shrinkage test assembly. A Transducer; B, test specimen; C, cover slip; D, brass support ring; E, rigid glass plate; F, light optic; and G, height adjustment screw.

Seven disc-shaped composite resin samples were fabricated from each composite resin shade, measuring 1.5×8 mm.

Group BW: The anterior G-aenial composite resin (BW shade) (GC Corporation, Tokyo, Japan).

Group A2: The posterior G-aenial composite resin (A2 shade) (GC Corporation, Tokyo, Japan).

The samples were placed at the center of a brass ring with 16 mm diameter and 1.5 mm height and mounted on a microscope slide. The slides with the samples were placed on the

special jig of a linear variable differential transformer machine designed to allow the specimens to be irradiated and illuminated from below (Figure 1). To prevent surface oxidation, a microscope slide with 0.13 mm thickness was placed on each sample. The LED source (Bluephase, Ivoclar Vivadent, Liechtenstein) that was stabilized under the glass slab was turned on in the standard curing mode, with an intensity of 750 mW cm^2 for 20 seconds. The tip of the linear variable differential transformer machine convertor was placed in contact with the composite resin disc, and connected through a data acquisition system to a computer. The data were continuously recorded for 10 minutes, consisting of 20 seconds of irradiation and 580 seconds of post-curing. The intensity of the light delivered by the light-curing unit was checked by a radiometer (Ivoclar Bluephase Meter II Vivadent, Amherst, NY, USA) before the irradiation procedure. According to Watts and Cash (17), the shrinkage occurs mainly in the vertical direction in this method. Therefore, the data show the vertical movement of the convertor's tip barely touching the surface of the glass slide on the composite resin, indicating the distance between the slide and sample surface at a micrometer scale, the change in the volume of the samples during polymerization (shrinkage reaction), and the conversion of $\text{C}=\text{C}$ Van der Waals bonds to covalent bonds. Therefore, when composite resin is light-cured, it is pulled upwards, and the extent of movement shows the polymerization shrinkage strain (Figure 2). The polymerization shrinkage rate was calculated up to 20 seconds (Figure 3)

$$\text{Polymerization shrinkage strain} = \frac{\text{the difference in height}}{\text{initial height of composited resin}}$$

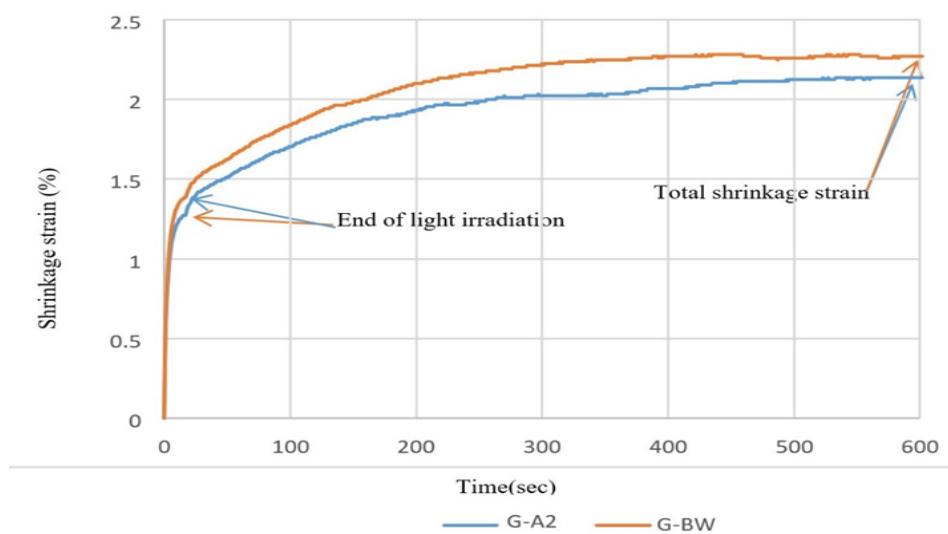
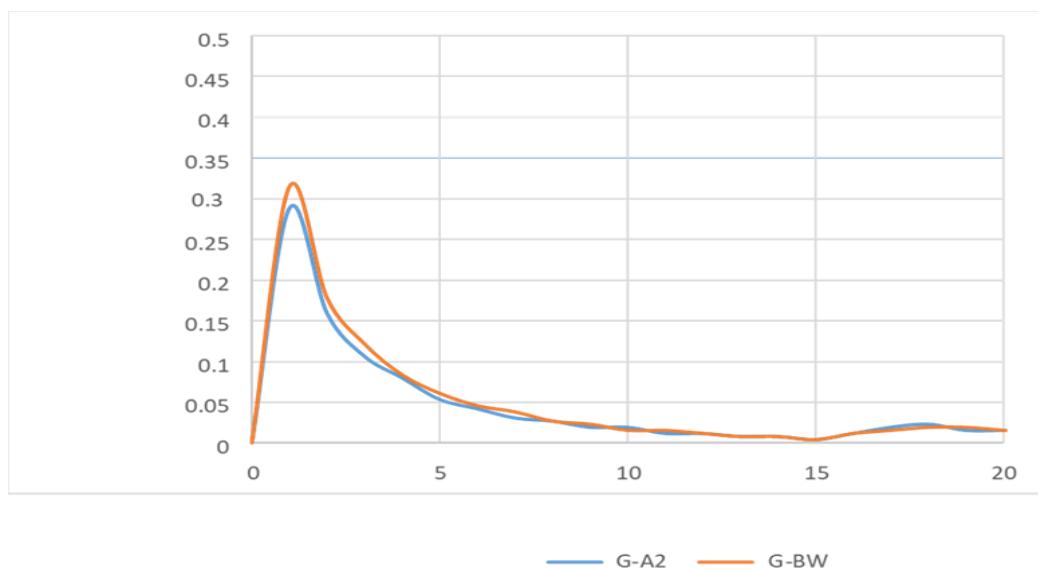
The Kolmogorov-Smirnov test was used to evaluate normal distribution of data. Data were analyzed by independent-sample t-test. The descriptive data were reported using descriptive statistics and measures of central dispersion (mean and standard deviation). The t-test was used to compare the groups. Statistical significance was set at $P<0.05$.

Table 1. Composition of materials used in the present study (18)

Composite	Manufacturer	Resin matrix	Filler content	Type
A2 G-eanial Posterior(GA-P)	GC, Corporation, Tokyo, Japan	UDMA*, dimethacrylate, Bis-GMA** free	Fumed silica, fluroaluminosilicate 76%	Micro-hybrid conventional
BW G-eanial Anterior(GA-A)	GC, Corporation, Tokyo, Japan	UDMA, dimethacrylate, Bis-GMA free	Fumed silica, silica 76%	Micro-hybrid conventional

*urethane dimethacrylate

** 2,2-bis [p-(2'- hydroxy-3'-methacryloxypropoxy) phenylene] propane

**Figure 2.** Real-time shrinkage strain (%) up to 600 seconds**Figure 3.** Rate of shrinkage strain (%/s) versus time up to 20 seconds

Results

Table 2 compares G-aenial anterior and posterior composite resins with A2 and BW shades concerning polymerization shrinkage using a LED curing unit. According to independent t-test, at 20 seconds and 600 seconds, there was no significant difference in polymerization shrinkage between the BW and A2 shades of G-aenial composite resin (Table 2). Up to 600 seconds, the maximum

polymerization shrinkage strain was evaluated between the two groups, but no significant difference was found (Table 2).

The maximum polymerization shrinkage rate was compared for up to 20 seconds between the two groups, but no significant difference was found ($P=0.50$).

Polymerization shrinkage strain increased significantly in both groups during the post-curing phase ($P<0.0001$, Table 3).

Table 2. Mean polymerization shrinkage strain of composite resin with A2 and BW shades (n=7)

Time	Composite color	Min.	Max.	Std. deviation	Mean	P value
20 sec	WB	1.24	1.51	0.105	1.420	0.955
	A2	1.22	1.79	0.214	1.390	
600 sec	WB	1.89	2.41	0.190	2.246	0.325
	A2	1.74	2.52	0.309	2.078	

Table 3. Comparison of mean polymerization shrinkage of each group at 20 and 600 seconds

Composite color	Time	Number	Mean	Sd.	Min.	Max.	Pvalue
A2	20 sec	7	1.3908	0.97	1.22	1.79	0.0001
	600 sec	7	2.0789	0.28	1.74	2.52	
BW	20 sec	7	1.420	0.09	1.24	1.51	
	600 sec	7	2.246	0.174	1.89	2.41	0.0001

Discussion

Polymerization shrinkage is one of the most important disadvantages of the currently available composite resins which might lead to marginal gap, postoperative sensitivity, enamel cracks, and recurrent caries (19). Additionally, composite resin shade is another important factor affecting the mechanical properties of light-cure composite resins (19). This study aimed to assess the effect of shade on immediate and post-curing shrinkage of different shades of composite resins.

Based on the results of the present study, the polymerization shrinkage of the two shades of the composite resin was not significantly different, which was in line with the findings of Jeong et al (20). They reported that in composites with the same filler and monomer content, the color difference had a minimal effect on polymerization shrinkage. According to the present results, the null hypothesis of the present study was accepted.

As stated by Cetin and Unlu, Some factors affecting

polymerization shrinkage are the light intensity, duration of irradiation, and the distance between the light-curing tip and the composite resin surface (21). The present study used one single LED curing unit for all specimens. Also, the distance from the light curing tip to the surface of samples was the same in all specimens, and light-curing time, ambient temperature, and the brand of the two shades were all the same. Thus, only the effect of shade was evaluated on polymerization shrinkage. In addition, the monomer and filler contents were the same in both groups (18). The inorganic filler in the BW Anterior composite resin is silica, and in the A2 shade posterior composite resin, fluoroaminosilicate is used as an opacifier. However, different shades of composite resins contain different types and amounts of pigments (1).

Contrary to the present study, Akan (22) and Al-Qudah et al. (23) stated that composite resins with brighter colors had a higher degree of conversion, and presence of less free radicals and higher opacities and less light transmission in darker composites were the reasons for the reduction in degree of conversion of darker shades of composites. Polymerization shrinkage and degree of conversion are directly correlated, and composite resins with a higher degree of conversion exhibit higher polymerization shrinkage rate.

Attempts have been made to reduce the reaction rate in early stages of reaction to minimize polymerization stresses (24). According to Figure 2, the shrinkage increased in both groups during the first few seconds. The slope decreased and increased a little up to 600 seconds at the turning point. Continuation of polymerization after the irradiation step is referred to as post-polymerization. According to Ide et al., maximum polymerization occurs in the first minutes after irradiation (25); in their study, the composite resin degree of conversion was measured up to 24 hours after the initial irradiation.

Figure 3 illustrates the polymerization shrinkage rate of the two composite resins up to 20 seconds in the present study. The ascending

and descending parts showed the polymerization rate during the first seconds of the light-curing process. In the ascending parts (auto-acceleration), the shrinkage rate increased rapidly. In the gel phase, although the movement of radicals is restricted, the ends of the polymer chains find each other later and the termination rate decreases, since the monomers are small and active, the polymerization rate increases, leading to the maximum point that vitrification occurs.

The composite resin's viscosity increases and the polymerization rate decreases rapidly. This stage is called the auto-deceleration stage. These two stages occur at <10 seconds, and after that, shrinkage continues at almost a constant rate. The graph's point of maximum shrinkage rate is the turning point in the shrinkage strain graph, at which the curve slope changes (26, 27). This observation was similar to studies by Ataei et al (26, 27). Lengthening the pre-gel stage makes it possible to decrease the shrinkage and stress resulting from the polymerization process (28). The shrinkage rate was not significantly different between the two groups in the present study.

The produced stresses depend on the kinetics of the polymerization reaction, which might be affected by several factors, including the type and intensity of the light source, the charge, shade, and concentration of initiator (diketone), the initiator (tertiary amine), inhibitors, and the type of monomer used (19). Polymerization shrinkages of both groups was approximately the same, which might be attributed to their similar filler volume and monomer (this composite resin has methacrylate and UDMA monomer). Alshaafi carried out a review study. They reported that the composite resin translucency significantly affected the transmission of light through the thickness of composite resin and that the shade did not considerably affect it (1). On the other hand, Faria-e-Silva et al. evaluated the effect of different shades of composite resins on the degree of conversion of monomers. The results showed that the degree of conversion significantly depended on the light's penetration capacity into composite resin

materials, which, *per se*, is related to transparency and the resin's filler system (3). Guraldo et al. reported that due to the opacity of the darker shades, light transmission decreases during the penetration of light. The polymerization initiation rate depends on the light intensity; therefore, a decrease in light intensity reduces the degree of conversion, decreasing polymerization shrinkage (29). This is different from the results of the present study. The almost similar filler content and the similarity of the matrix of the two composite resins may play an important role in polymerization rate of composite resins. Fillers comprise a significant volume or weight of composite resins. Their function is to strengthen the resin matrix, create a proper degree of transparency, and control the volumetric shrinkage of composite resins during polymerization. In the present study, the filler content of composite resin was almost similar in both groups (65 vol% of filler for the A2 shade of G-aenial GAP and 63 vol% of filler for the BW shade G-aenial G-AA). Therefore, they had an almost similar degree of conversion and polymerization shrinkage. In a study by Mousavinasab et al (4), the degree of conversion in the light B2 shade was slightly higher than the dark A3 shade, attributed to the darker pigments that absorb light. Lower rates of free radicals lead to a lower degree of conversion, and as discussed above, a higher degree of conversion leads to higher polymerization shrinkage (4). Therefore, longer irradiation times are recommended for darker shades than light shades. Although polymerization shrinkage with the lighter BW shade was higher than the darker A2 shade in the present study, the difference was not significant.

Similar to the present study, Jeong et al. compared the maximum polymerization shrinkage of composite resins. The B3, A3.5, A3, and C3 shades of Z250 composite resins did not exhibit significant differences using a quartz-tungsten-halogen light-curing unit. However, the maximum polymerization shrinkage rates of B3, A3.5, A3, and C3 shades of Solitaire composite resin were significantly

different, at a minimal level. Such differences might be attributed to the microfiller particle content and the monomer content and formation of composite resins or the higher diluent content in the Solitaire composite resin (30). On the other hand, Akan reported that higher shades had lower polymerization shrinkage, different from the present study (22).

In the present study, although an attempt was made to eliminate confounding factors to achieve more reliable results, there were limitations in the study setup. The temperature during the curing measurements did not simulate the clinical conditions. All the measurements were carried out at room temperature, while the oral cavity temperature is 36°C.

Conclusion

In conclusion, the findings of the present study showed that the polymerization shrinkage strain of G-aenial composite resin was not affected by shade. However, in both composite resin shades, polymerization shrinkage immediately after irradiation and 600 seconds after that showed a significant difference, indicating continuation of polymerization after terminating the irradiation procedure and the importance of post-curing period in posterior and anterior composite resins.

Ethics approval and consent to participate

The Ethics Committee of Ahvaz Jundishapur University of Medical Sciences approved this study (IR.AJUMS.REC.1395.177)

Availability of data and material

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that they have no competing interests.

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