

EFFECT OF PLASMA AND HALOGEN LIGHT-CURING UNITS ON SHRINKAGE STRESS PHENOMENA.

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Abstract

Objectives: To investigate the stresses generated during the light-curing of resin composites with a plasma light-curing unit (LCU) and a halogen LCU using a micro-strain technique.

Methods and Materials: Three different classes of composites were tested: traditional composites, condensable composites and flowable composites. Samples (n=6) were light cured with a halogen light at a constant power (500 mW/cm²) and a plasma source unit: the first step at medium power and the second at high power. A sample was positioned on an aluminium plate. A strain gauge positioned under the aluminium plate measured the deformation of the plate during light-curing. Maximum interfacial stress was evaluated by using a mathematical model of a simply supported beam.

Results: With all the tested materials, the samples cured with the halogen light showed significant statistically higher strain values than the samples cured with the plasma light.

Discussion: The plasma curing unit resulted in lower shrinkage stress values than those resulting from the halogen unit and the relaxation time of the condensable materials was lower than the traditional ones.

Conclusions: Plasma LCU produces a low degree of shrinkage when compared to halogen LCU. Heat developed during a halogen light-curing procedure significantly influences composite shrinkage phenomena, whereas this does not occur with the use of a plasma light-curing unit.

Clinical Significance: Heat developed during a halogen light-curing procedure significantly influences composite shrinkage phenomena. Heat developed during short-time plasma light-curing procedures does not influence composite shrinkage phenomena.

Key words: biomaterials, shrinkage, dental composites, curing unit.

Running title: Shrinkage of composites with different light-curing units.

Introduction

The current generation of dimethacrylate based composite-resins used in restorative dentistry has the inherent property of polymerization shrinkage, which produces a volumetric change and distributes contractile stresses through the resin-hard tissue interface into the tooth. Gaps occur at the interface between the restoration and the remaining tooth structure when the

enamel or dentine bond strength is inadequate to withstand polymerization contractile stresses.¹ The gaps result in bacterial microleakage, which may be an aetiological factor in pulpal pathology.² If the bond strength is adequate, the contraction stresses are transmitted to the remaining tooth structure and may result in enamel microcracks at the cervical areas. Polymerization shrinkage has also been implicated in post-operative sensitivity of composite restorations.³ Progress towards the elimination or reduction of polymerization contraction by synthesis of monomers that expand upon polymerization has been reported by Thompson et al.⁴ and Stansbury,⁵ but such monomer systems have not yet been incorporated into dental materials due to clinical restrictions on the permissible curing temperature.

Polymerization shrinkage strain is a time dependent phenomenon and generally proceeds in two stages: pre-gel and post-gel (i.e. vitrification) contraction.² The stage of shrinkage which occurs before the polymerization gel point does not induce stress and the volumetric change can be partly compensated by the immediate flow of the composite paste.

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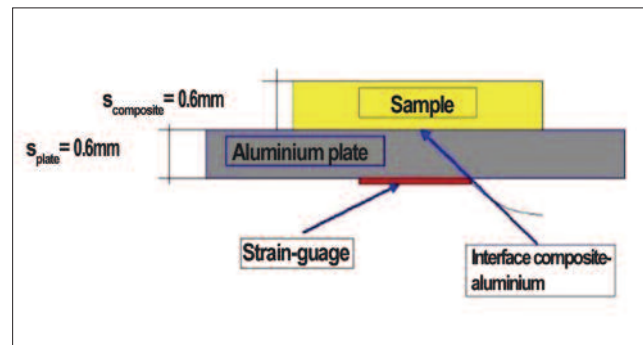


Figure 1. The scheme of the measurement strain-gauge system.

Following gel formation, the polymerization process is accompanied by a rapid increase in the modulus of elasticity. Subsequent shrinkage can thus induce stress within the polymer and distribute it to the boundary layers. The adverse effects of polymerization shrinkage stress on the bond between restorative materials and hard tissues have been extensively described in the dental literature.⁶⁻⁹ The rates of development of kinetics of shrinkage strain and stress are also important parameters which merit attention. In light cured materials the light shielding effect on the depth of cure leads to anisotropy of the cure pattern with a possible variation of shrinkage patterns within the material, relative to the initiating light source.¹⁰ In cases where materials specimens are imperfectly cured, the measured shrinkage will be reduced correspondingly. Many approaches to the determination of material shrinkage have been reported in the dental literature: volume dilatometry,¹¹ non volume dilatometric methods, bonded-disk¹²⁻¹⁴ and the Archimedes principle. There are many studies comparing the polymerization of HTC and Plasma light-curing units on several properties of resin-based composites.¹⁵⁻¹⁸ Rueggeberg et al.⁶ reported that plasma arc exposure for less than 10 seconds produced inferior hardness compared with the conventional quartz tungsten halogen (QTH) units.

The aim of this study was to determine the stresses generated during light polymerization of resin-composites with two different light-curing units (halogen and plasma), using strain-gauge strain measurement. The strain gauge is extremely sensitive to linear dimensional changes, when it is bonded to a substrate. These linear dimensional changes in the substrate are efficiently transferred to the gauge and readily measured. The null hypothesis to be tested is that there are no differences in shrinkage stress induction between the two type of tested light-curing units.

Materials and Methods

The light sources used in this experiment were a halogen unit (Optilux 500, KerrHawe SA, Bioggio, Switzerland) and a plasma curing unit (Apollo 95E, Ideco, Bolzano, Italy).

Three different classes of commercial dental composites were tested: 1) traditional composites (Prodigy, KerrHawe SA,

Bioggio, Switzerland; Z 250, 3M ESPE, Segrate, Italy), b) condensable composites (Prodigy Condensable, KerrHawe SA, Bioggio, Switzerland; Solitaire, Heraeus Kulzer, Hanau, Germany; Pyramid, Bisco Inc., Schaumburg, IL, USA) and c) flowable composites (Revolution, KerrHawe SA, Bioggio, Switzerland).

Measuring system

A strain-gauge was glued to an aluminium plate, which served as a measuring support for the composite samples. The upper-surface of the aluminium plate was abraded and cleaned in order to improve the adhesion of the composite samples. The dimensions of the aluminium plate were 20mm · 10mm · 0.6mm. A strain gauge (CEA-06-032UW-120, Vishy Measurements Group, Inc, NC, USA) was positioned on the bottom surface of the aluminium plate by recommended adhesive (Type 200 Vishy Measurement Group, Inc, NC, USA).

Preparation of samples and positioning on the measuring system

A circular aluminium ring served as a mould for the preparation of the composite samples. The internal dimensions of the aluminium ring were 10mm in diameter and 0.6mm in height. The ring was positioned on the abraded upper surface of the previously described aluminium plate. The un-polymerized composite was positioned and fitted in the aluminium ring. Particular attention was paid to the flattening of the upper surface of the un-polymerized composite mass (that being irradiated by the light source). The ring was equipped with a fast opening system in order to be easily removed by the moulded composite without modifying the composite sample shape. After the removal of the aluminium ring, a composite plate remained on the abraded upper-surface of the aluminium plate. The dimensions of the composite sample mass were 10mm in diameter and 0.6mm in height. With the strain-gauge positioned on the bottom surface of the aluminium plate, the system (Figure 1) was ready to measure the deformation of the aluminium plate determined by the composite polymerization shrinkage along the gauge-axis.

Measuring procedure

Once the sample was positioned on the measuring system, the strain-recording apparatus was initiated to capture the deformation induced by the composite shrinkage under the irradiation source, as well as the other phenomena occurring after the irradiation time elapsed. The duration of the overall measurement was 200 s.

Six samples of each material were cured at a distance of 1 cm from the light-curing unit with a halogen light at 500 m W/cm² for 60 seconds. Six samples of each material were cured at a distance of 1 cm from the light-curing unit with a plasma light at a step cure method (1000 m W/cm² for 3 seconds and > 1000 m W/cm² for a further 3 seconds), as recommended by the manufacturer.

The deformation in the time was recorded by an acquisition data software (System 4000 with 20 input channels by Vishay Measurements Group, Inc, NC, USA) at 2 points per second, for 200x.

The maximum interfacial stress was evaluated by a mathematical model of a simply supported beam from the experimental strain data.

Polymerization strain measurements

From the experimental evaluation of the variation of the strain during the time, measured with the strain gauge method, the polymerization shrinkage kinetics and the maximum polymerization strain for all materials were estimated. The experimental data (i.e. strain) were normalized on the mean thickness of the composite samples, by calculating the average thickness of the sample, after measuring it in 5 points (Digital Micrometer, Mitutoyo Ltd, Andover, UK).

Mathematical model of interfacial stress evaluation

To evaluate the interfacial stress, a simple analytical model has been developed based on the Navier beam-bending theory (Figure 2). The hypotheses of formulation were the following:

- shrinkage is uniform over the interface;
- there is no slip between composite and substrate at the interface (i.e. perfect adhesion);
- the only mechanical effect of the polymerization shrinkage is the application of the bending and compression load on the substrate, so that the stress and strain distributions are linear in the section.

The stress induced on a beam subjected to bending and a compressive load **N** is given by (1):¹⁹

$$\sigma = -\frac{M_{Gy}}{J_y}x + \frac{M_{Gx}}{J_x}y + \frac{N}{A}$$

Where **A** (axb) is the section area, **NMGx** and **MGy** are the resulting compressive loads and the two components of the bending moments due to composite shrinkage and **Jx** and **Jy** are the moments of inertia of the cross-section. From the hypothesis the bending moments are: **MGx=Nxb/2**, **MGy = 0** and the equation (1) becomes (2):

$$\sigma = \frac{N(t) \cdot b/2}{J_x}y + \frac{N(t)}{A}$$

The **y** position of the neutral axis of the stress distribution expressed by the equation (2) is calculated from the condition **σ = 0**. The interfacial strain **ε_{int}** (i.e. strain at top surface of aluminium plate) and interfacial stress **σ_{int}** are evaluated from the linear strain Navier distribution hypothesis, the position of the neutral axis, the experimental value of strain **ε_{exp}** and the value of Young's modulus of aluminium **E**. In formula:

- **y** position of neutral axis: (3)

$$y = \frac{b}{6}$$

- Linear strain distribution across substrate section and the interfacial strain **ε_{int} = -b/2**: (4)

$$\epsilon(y) = \frac{3\epsilon_{exp}}{b}y - \frac{\epsilon_{exp}}{2} \Rightarrow \epsilon(b/2) = \epsilon_{int} = -2\epsilon_{exp}$$

- Interfacial stress on substrate (absolute values): (5)

$$\sigma_{int} = 2E\epsilon_{int}$$

One-way ANOVA analysis for independent samples was performed on experimental data with p<0.05.

Results

The polymerization strain curves of all the tested materials have been reported in Figures 3 and 4, respectively, for the halogen and plasma curing units. A characteristic of the shrinkage curve recorded for the halogen light-curing unit is shown in Figure 5. A comparison between the effect of the halogen and plasma light-curing units on the polymerization strain curve of Prodigy Condensable, Prodigy and Revolution shrinkage-strain values is reported in Figure 6. With regard to the halogen light-cured specimens, the value ranged from 337 to 414 με after 200s, while the plasma light-cured specimens ranged from 107 to 288 με.

In all the experimental groups, samples cured with the

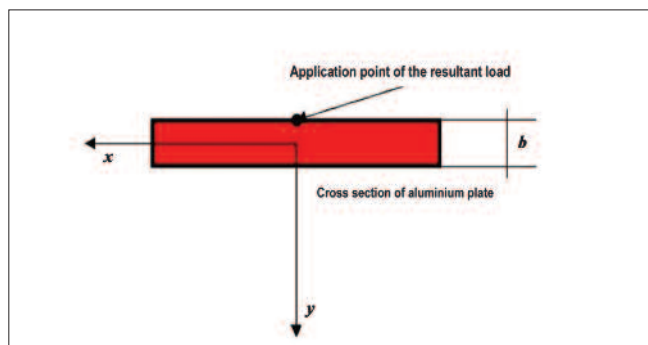


Figure 2. The cross section of the substrate.

halogen light showed significantly higher strain values than the samples cured with the plasma light (Table 1).

Discussion

According to the applied method, the aluminium plate deformation was measured during the irradiation time and after the irradiation time. For each experiment the overall measuring time was 200s. The strain gauge method is a valid tool to measure the polymerization shrinkage strain of resin composites. Polymerization was not free since the aluminium plate represented an elastic constraint. The evaluation of polymerization shrinkage in non-free conditions allows the interfacial stress to be estimated, which, conversely, cannot be evaluated by means of the free shrinkage method.^{20,21}

It has been proven that plasma LCUs produce more heat when compared with HTC LCUs because of the higher output (more than 1000 mW/cm² vs 500 mW/cm² respectively).¹⁶⁻¹⁸

Nomoto et al.²³ measured that the temperature increased from 15°C to 60°C during curing irradiation with a plasma LCU, whilst they measured a rise of 15°C for a HTC unit in the same conditions. There were no direct exotherm measurements in this study, although the indirect effect of heat could be observed. This was clearly shown in the HTC unit shrinkage measurement. In all of them a side-step was clearly

recorded at the end of irradiation time (60s in the case of the HTC irradiation). The combined effect of light and heat contributes to the polymerization of composite resins. Thus, the side-step is due to the removal of heat from the system and to the fact that the beneficial effect of expansion can no longer be utilized. This side-step was not evident in the plasma shrinkage measurements, which was probably due to the short irradiation time (i.e. 6s) rather than to the absence of heat in the plasma units. Such a phenomenon was not an artefact but a real change and caused an abrupt variation in the shrinkage curve of the halogen LCU as shown in Figure 5. To minimize the effect of heat on the strain gauges themselves, they were calibrated and self compensated for temperature. In fact, they demonstrated a very flat response in the temperature range of interest.

For all the tested materials, the samples cured with the halogen LCU showed significant statistically higher strain values than the samples cured with the plasma LCU (Figure 6, Table 1). In agreement with Sakaguchi et al.,²⁵ such a phenomenon was probably due to the low degree of conversion obtained with the plasma irradiation when compared with the halogen curing.²⁴

According to the results of the present investigation, the null hypothesis of no influence of the type of light-curing unit on the shrinkage phenomena of light polymerized resin-based composites was rejected.

The highest interfacial stress during halogen LCU irradiation was reached by the composite, Pyramid. Such stress value was significantly higher than those recorded for Revolution, Solitaire, Prodigy Condensable and Prodigy, while among these, no significant statistical differences were found. A lower interfacial stress was recorded for Z250, the value of which was not statistically different from those observed for Prodigy Condensable, Prodigy and Solitaire, while a statistical significance was appreciable when compared to Pyramid and Revolution.

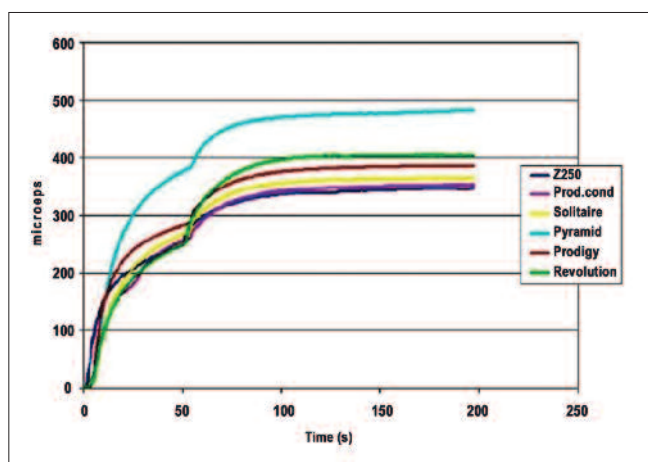


Figure 3. The shrinkage curve of the halogen curing process.

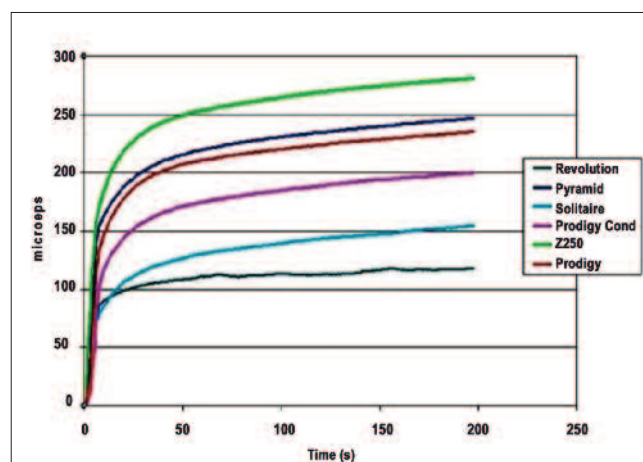


Figure 4. The shrinkage curve of the plasma curing process.

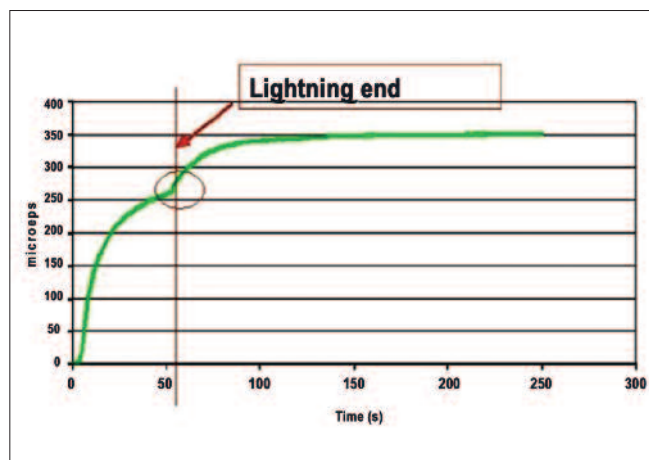


Figure 5. The effect of the radiant heat due to the halogen curing process.

Regarding the plasma irradiations, Z250 showed significantly higher interfacial stresses than those observed for the other tested samples. The lowest shrinkage stress was observed for Revolution. It is worth noting that the material showing the highest interfacial stress in the halogen cured group did not maintain the same behaviour in the plasma cured group. This phenomenon was observed for all the tested materials. Since the only difference among the two groups was the type of light-curing unit used, it could be hypothesized that the polymerization rate, and thus the shrinkage velocity, significantly affected the final interfacial stress by acting on the composites relaxing capability. It is of interest to note that materials with a low modulus of elasticity (i.e. Revolution) produced stress values higher than materials with higher modulus of elasticity.

Despite differences in their moduli of elasticity, conclusions taking in account exclusively this parameter cannot be inferred. The results of the present study suggest that not only the

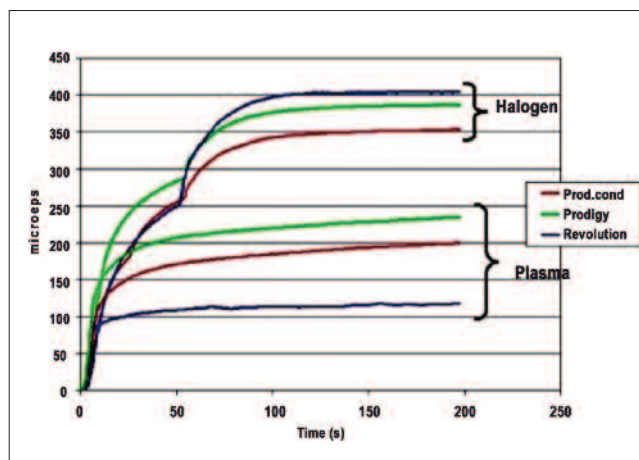


Figure 6. The shrinkage comparison between halogen and plasma light-curing units.

elastic component of the complex modulus should be considered in the polymerization shrinkage phenomena of dental composites. On the other hand, the viscous contribution is not only dependent by the filler/matrix ratio. Time dependency is the essence of viscosity, thus the polymerization velocity should also be considered in the composite relaxation phenomena. Two variables can affect the polymerization rate and, consequently, the shrinkage rate: the light-curing unit and the composite composition in terms of initiator and catalyst. Since the LCU variable was controlled in the present study, the observed effects should be attributed to the composition of the tested composite.

Conclusions

Within the limitations of the present in vitro study, the following conclusions can be drawn:

- the plasma LCU used for short irradiation times produces a low degree of shrinkage when compared to the halogen LCU

| Table 1. Interfacial strain (ϵ_{int}) and interfacial stress (σ_{int}) values measured in $\mu\text{m/m}$ (\pm standard deviation) for each composite material after 200s of irradiation with different LCUs. | | | | |
|--|--------------------------|------------------------|-------------------------|-----------------------|
| Material | Halogen ϵ_{int} | Halogen σ_{int} | Plasma ϵ_{int} | Plasma σ_{int} |
| Prodigy | 387 \pm 43 | 54 \pm 6 | 235 \pm 30 | 33 \pm 4 |
| Prodigy Condensable | 353 \pm 35 | 49 \pm 6 | 203 \pm 30 | 28 \pm 0.4 |
| Z 250 | 337 \pm 15 | 47 \pm 2 | 281 \pm 11 | 39 \pm 2 |
| Solitaire | 364 \pm 33 | 51 \pm 5 | 247 \pm 15 | 35 \pm 2 |
| Pyramid | 464 \pm 11 | 65 \pm 2 | 155 \pm 10 | 22 \pm 1 |
| Revolution | 406 \pm 21 | 57 \pm 3 | 107 \pm 14 | 15 \pm 2 |

used for conventional time (60s);

- the heat developed during a halogen curing procedure significantly influences the composite shrinkage phenomenon;
- the heat developed during short time plasma light-curing procedures does not influence the composite shrinkage phenomenon.

References

1. Ozturk AN, Usumez A. Influence of different light sources on microtensile bond strength and gap formation of resin cement under porcelain in lay restorations. *J Oral Rehabil* 2004; 31:905-910.
2. Bausch JR, De Lange K, Davidson CL, De Gee AJ. Clinical significance of polymerization shrinkage of composite resins. *J Prosthet Dent* 1982;48:59-67.
3. Eick JD, Welch FH. Polymerization shrinkage of posterior composite resins and its possible influence on post operative sensitivity. *Quintessence Int* 1986;17:103-111.
4. Thompson VP, Williams EF, Bailey WJ. Dental resins with reduced shrinkage during hardening. *J Dental Res* 1979;58:1522-1532.
5. Stansbury JW. Cyclopolymerizable monomers for use in dental resin composites. *J Dent Res* 1990;69:844-848.
6. Feilzer AJ, De Gee AJ, Davidson CL. Setting stress in composite resin in relation to configuration of the restoration. *J Dent Res* 1987;66:1636-1639.
7. Nilgun Ozturk A, Usumez A, Ozturk B, Usumez S. Influence of different light sources on microleakage of class V composite resin restorations. *J Oral Rehabil* 2004;31:500-504.
8. Kubo S, Yokota H, Yokota H, Hayashi Y. The effect of light-curing modes on the microleakage of cervical resin composite restorations. *J Dent* 2004;32:24-54.
9. Abbas G, Fleming GJ, Harrington E, Shortall AC, Burke FJ. Cuspal movement and microleakage in premolar teeth restored with a packable composite cured in bulk or in increments. *J Dent* 2003;31:437-444.
10. Watts DC, Cash AJ. Determination of polymerization shrinkage kinetics in visible light-cured materials: method development. *Dent Mater* 1991;7:281-287.
11. Bang HC, Lim BS, Yoon TH, Lee YK, Kim CW. Effect of plasma arc curing on polymerization shrinkage of orthodontic adhesive resins. *J Oral Rehabil* 2004;31:803-810.
12. Silikas N, Al-Kheiraf A, Watts DC. Influence of P/L ratio and peroxide /amine concentrations on shrinkage-strain kinetics during setting of PMMA/MMA biomaterial formulations. *Biomaterials* 2005;26:197-204.
13. Silikas N, Eliades G, Watts DC. Light intensity effects on resin-composite degree of conversion and shrinkage strain. *Dent Mater* 2000;16:292-296.
14. Kakaboura A, Rahiotis C, Zinelis S, Al-Dhamadi YA, Silikas N, Watts DC. In vitro characterization of two laboratory-processed resin composites. *Dent Mater* 2003;19:393-398.
15. Jain P, Pershing A. Depth of cure and microleakage with high-intensity and ramped resin-based composite curing lights. *J Am Dent Assoc* 2003;134:1215-1223.
16. Rueggeberg FA, Ertle JW, Mettenberg DJ. Polymerization depths of contemporary light-curing units using microhardness. *J Esthet Dent* 2000;12:340-349.
17. Price RB, Ehrnford L, Andreou P, Felix CA. Comparison of quartz-tungsten-halogen, light-emitting diode, and plasma arc curing lights. *J Adhes Dent* 2003;5:193-207.
18. Katahira N, Foxton RM, Inai N, Otsuki M, Tagami J. Comparison of PAC and QTH light sources on polymerization of resin composites. *Am J Dent* 2004;17:113-117.
19. V. Franciosi. *Fondamenti di scienza delle costruzioni*, 1987; 2-165.
20. De Gee AJ, Davidson CL, Smith A. A modified dilatometer or continuous recording of volumetric polymerization shrinkage of composite restorative materials. *J Dent* 1981;9:36-42.
21. Bekkedahl N. Volume dilatometry. *J Res National Bureau of Standards* 1949;42:145-156.
22. Ozturk B, Ozturk AN, Usumez A, Ozer F. Temperature rise during adhesive and resin composite polymerization with various light-curing sources. *Oper Dent* 2004;29:325-332.
23. Nomoto R, McCabe JF, Hirano S. Comparison of halogen, plasma and LD curing units. *Oper Dent* 2004;29:287-294.
24. Di Palma L, Apicella A, Cascone P, Ausiello P, Rengo S. "DSC kinetic characterisation of dental composites using different light sources". *Proceedings of 32nd SAMPLE Technical Conference Boston* (2000).
25. Sakaguchi RL, Sasik CT, Bunczak MA, Douglas WH. Strain gauge method for measuring polymerization contraction of composite restoratives. *J Dent* 1991;19:312-316.