Optimization of the composite resins photoactivation process by a computational controller system

Pedro H. Affonso[a], Gabriel Guimarães[a], Gabriel Cardoso[a], Edilmar Marcelino[b] and Rafael P. Simões[a 1]

[a]College of Agricultural Sciences, UNESP Univ Estadual Paulista, Botucatu, SP, Brazil

[b]College of Medicine, UNESP Univ Estadual Paulista, Botucatu, SP, Brazil

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Abstract

The shrinkage is an intrinsic behaviour in the dental composite resins caused by the volumetric variation due the photopolymerization process, which can eventually induce some adherence flaws in the area between the resin and tooth. To minimize this effect, an alternative curing light device and a computational interface to select the photoactivation parameters were developed using Arduino technology. This device allows modulating the variation of the luminous intensity during the photoactivation process by an optimized mathematical function. The use of the proposed alternative device resulted in the reduction of approximately 45% of the contraction stress, without affect the mechanical properties of the polymerized resins.

Keywords: photopolymerization, computational optimization of objective functions, computational control of process, polymerization shrinkage, dental restorations.

1. Introduction

Prior to the development of composite resins in 1962, the amalgam was the most used material for dental restorations, especially in posterior teeth[1]. Although it has a great mechanical strength, marginal integrity and durability, the amalgam has an unsatisfactory esthetic result[2].The emergence of the composite resins made possible provide more esthetic quality to dental restorations. However, the mechanical properties of the resins, especially the high levels of contraction stress by volumetric variations during the activation process are the principal problem in the use of this kind of material[3, 4, 5, 6].

[1]E-mail Corresponding Author: rafael@fca.unesp.br

Despite the advances in resins for minimization of the polymerization contraction, this problem still persists and can cause micro infiltrations in the marginal adhesive interface, harming the esthetics of the restoration and, in some extreme cases, favouring the growing of bacteria.[7, 8]

Seeking efficiency and quality, various efforts have been made to reduce the effects of polymerization shrinkage. The current approaches are the improvement of the chemical composition of the resins, the photo-initiator molecules and the polymerization process catalysts.[9, 10]

However, some studies show that the variation of some physical parameters can change significantly the resin contraction during the curing process. The results from Baseggio[11] concluded that the luminous density power of the curing device has correlation on the induction of the volumetric contraction of photopolymerized composite resins. Ishikiriama et al.[12] studied the variation of contraction stress in polymerized resins under different conditions of its exposure to the luminous source. Both researches showed that the variation of the light intensity pattern during the polymerization process has an influence on the values of contraction stress. However, this kind of study is limited by the operational functions of the curing light devices available.

In this way, to be carried out further studies of the influence of light intensity and exposure time on the polymerization shrinkage of the composite during the curing process, it is necessary a curing light device with a controller which allows to vary continuously the luminous intensity during this process. Thus, this study presents a numerical approach to determine an optimal mathematical function of the light intensity in the time domain to minimize the effects of polymerization shrinkage in curing processes of composite resins. A prototype of a curing equipment of dental resins, operated by a computer interface, was developed incorporating features to control the light intensity using mathematical functions. The mechanical properties of the polymerized resins were evaluated to compare the quality of composite resins polymerized by the equipment and protocols developed during this research and the quality of the resins polymerized using a conventional curing device.

2. Methods

Determination of the optimal mathematical function to minimize the polymerization shrinkage

The determination of the mathematical dimming function in the time domain to minimize the shrinkage stress is based on the results obtained by

Ishikiriama et al. [12] in curing process of composite resins. The reported results show the dependence of shrinkage stress (f_c) with the time (t) for a photoactivation process with continuous luminous intensity of the LED (i) during the process. Therefore, it assumes the existence of a function described as $f_c(i, t)$ which represents the behavior of the shrinkage stress. The minimization of shrinkage stress, thus, can then be modeled mathematically by an optimization problem of an objective function.

An Octave interpolation script was applied to determine the function $f_c(600, t)$. In the sequence, the same software was utilized for the function minimization process, which consists in calculating the polymerization shrinkage instantaneous rate as a function of time, $\frac{\partial f_c}{\partial t}$, and determining the inverse function of this contraction rate, $(\frac{\partial f_c}{\partial t})^{-1}$.

Hardware development

The hardware of the alternative curing device was developed using Arduino technology. The control system was provided by an Arduino Uno board, which was connected at a computer using an USB cable. However, the intensity of electrical current provided by the Arduino board is not capable of supplying the LEDs device. Thus, a 4 V / 2200 mAh battery and a MOSFET transistor were used in an auxiliary circuit.

A second generation LED was used as the light source, model LZ1-00DB00, from LED Engin Inc manufacturer. This LED model features high light power (10 W) and small size (4.4 mm x 4.4 mm), specially developed for this kind of application. The Figure 1 shows the diagram of the complete hardware project.

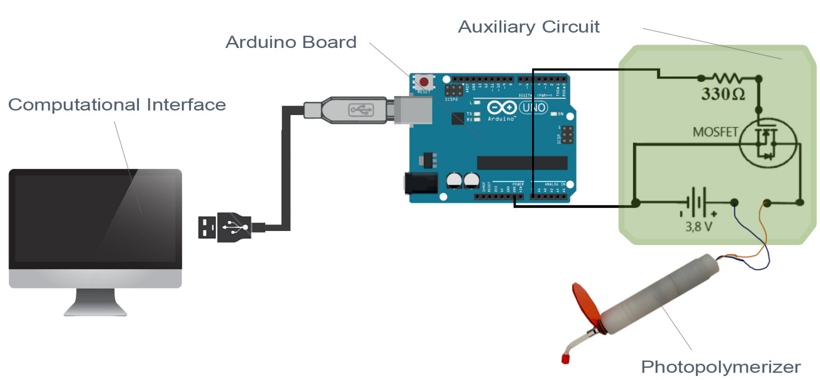

Figure 1 - Diagram of the hardware project.

Software Development

The software was developed to work as a controller to the luminous intensity of the light source (i.e., the second generation LED). It was developed using C++ script, which is compatible with the Arduino microcontroller. The software allows defining the luminous intensity variation (in mW/cm^2) by a mathematical function in the time domain. In this way, the software allows the use of the previously determined minimization function to investigate its application in a real curing light process.

In the software interface, the user can select the following polymerization parameters: polymerization time; initial and final luminous intensity; and the mathematical function to module the variation of the luminous intensity during the process. It is also possible to combine up to three steps per run, each one with different reported parameters. The Figure 2 shows a fluxogram that represents the software operating sketch.

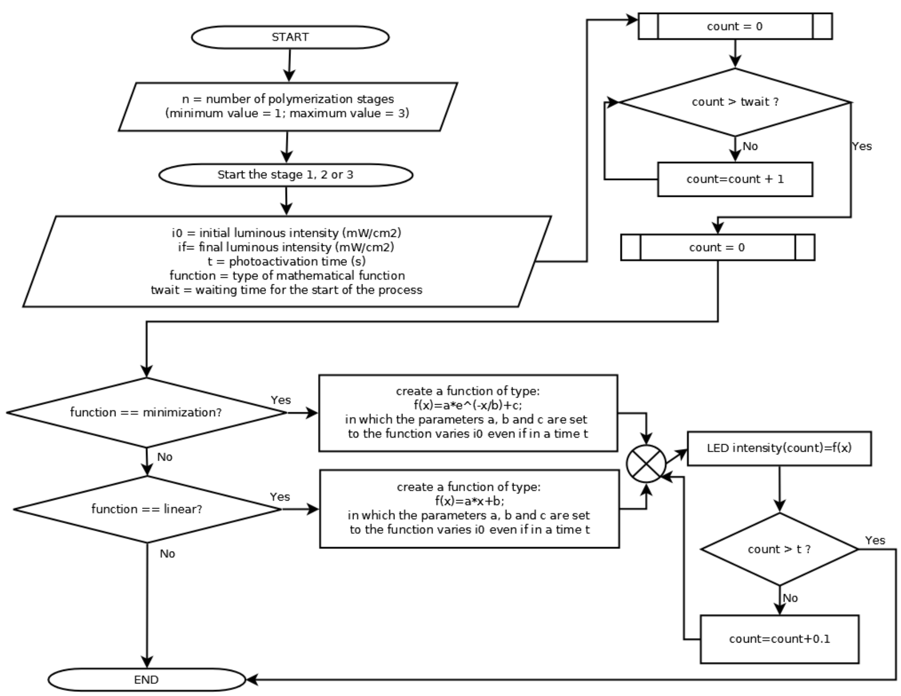

Figure 2 - Fluxogram of the software operating sketch.

Evaluating of the polymerization process and the quality of polymerized resin

All experiments were performed using the composite Filtek Z 250, from the 3M manufacturer. For comparison, the resins were light cured using the conventional method and minimization method (this last applying the optimized mathematical function for the luminous intensity variation).

The monitoring of shrinkage stress was performed in a universal testing machine Emic DL 500. An adaptation using two steel bases was coupled in the arms of the machine, and the arms were adjusted so that the resin can be inserted and polymerized for tests. The gap between the two stents in which the resin is inserted, is regulated with a length of 1 mm so that the specimen to be polymerized had the following dimensions: 6 mm x 2 mm x 1 mm. The device driver software traced a curve of the shrinkage force as a function of the polymerization time. The contraction stress was monitored by the equipment for 300 s from the start of the curing process.

However, the reduction of the shrinkage stress does not characterize an improvement in the polymerization process of the composites. In this way, a Scanning Electron Microscopy (SEM) analyses were performed in restoration of real human teeth. The volume of resin applied in the teeth restoration processes were the same used for the shrinkage stress tests.

By the end, the hardness of the polymerized resins was evaluated. For the hardness test, specimens with the same dimensions used in shrinkage stress test were made. These specimens had their surface hardness measured at three different points using a Shore D scale durometer of the Zwick manufacturer, DIN 53505 model.

3. Results

The experimental data from the shrinkage stress tests for the conventional process applying constant luminous intensity (600 mW/cm^2) was fitted by a first order exponential decay function:

$$f_c(600, t) = -8.45 \cdot e^{(-t/49.27)} + 7.95, \tag{1}$$

for which the determination coefficient was $R^2 = 0.99$. Thus, it was possible to determine the polymerization shrinkage instantaneous rate as a function of time:

$$\frac{\partial f_c}{\partial t} = 1.72 \cdot 10^{-1} \cdot e^{(-t/49.27)}. \tag{2}$$

Finally, the mathematical optimization resulted in a minimization function with exponential behaviour:

$$i(t) = a \cdot e^{t/b}, \tag{3}$$

where $a = 5.83$ and $b = 49.27$. This function represents an exponential growth of the luminous intensity in the time domain of the photoactivation process, and the constants a and b must be adjusted to comply with the specifications for polymerization of different resins brands and models. The results of this mathematical optimization are graphically illustrated in Figure 3.

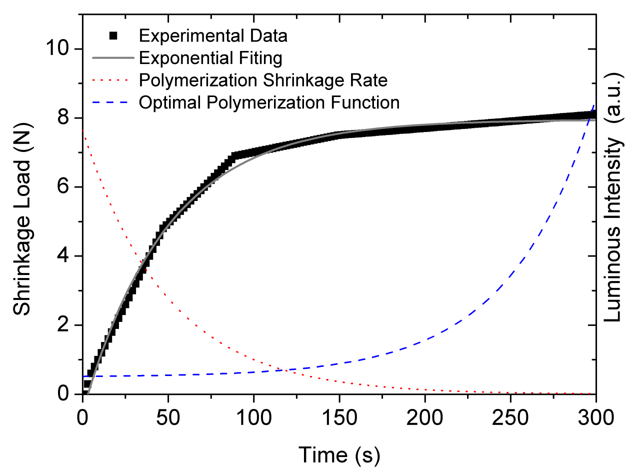

Figure 3 - Curves of: shrinkage stress for the conventional polymerization method; shrinkage rate and; shrinkage minimization function.

The called shrinkage minimization technique promoted a reduction of 45% of stress in the final of the polymerization process. The SEM analyses showed that this reduction of the stress promoted the elimination of cracks at the resin/tooth interface, which is shown in Figure 4.

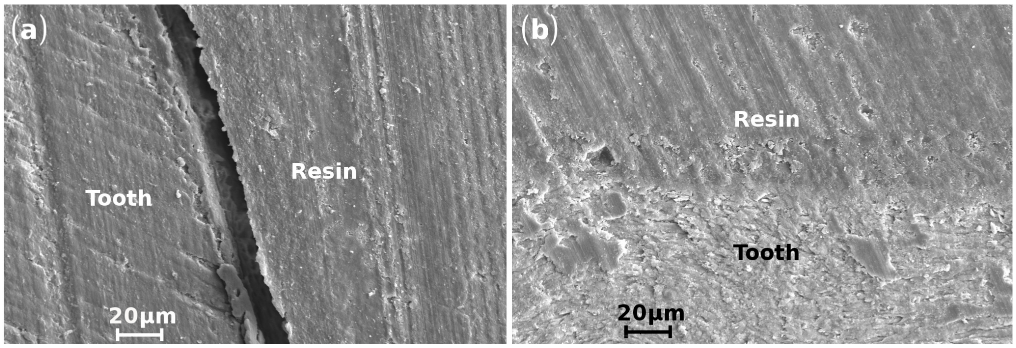

Figure 4 - SEM analyses of the resins light cured using: (a) the conventional method and; (b) the minimization method.

The results from hardness tests showed that this alternative polymerization method did not cause damage to the surface hardness of the cured resin. The surface hardness for the cured resins by the conventional method was 84.6 $\pm$ 2.0 Shore D, while, for the minimization method the hardness was 84.9 $\pm$ 2.0 Shore D. By the standard deviation, it be concluded the surface hardness is statically the same for both photoactivation processes.

4. Conclusions

The results obtained in this study show that the curing unit device developed in this study (with digital and continuous control functions of light intensity during the curing process) is more efficient than a conventional device for reducing the effects of polymerization shrinkage in composite resins used for dental restorations. By this result, it can be said that the light intensity during the curing process is directly related to the polymerization process, possibly altering the kinetics of chemical activation of monomer to polymer conversion. By the exposed, the developed device can be a viable for practical application in dental offices.

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