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Original article

Effects of low-energy electron beam irradiation on flexural properties of self-curing acrylic resin

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ARTICLE INFO

Article history:
Received 1 June 2013
Received in revised form
17 September 2013
Accepted 29 October 2013
Available online 3 January 2014

Keywords:
Self-curing acrylic resin
Low-energy electron beam
Polymer powder
Cross-linking
Flexural strength

ABSTRACT

Purpose: The purpose of this study was to confirm the effectiveness of LEB irradiation onto the polymer powder for improving the mechanical properties of self-curing acrylic resin.
Methods: The polymer powder of self-curing acrylic resin was irradiated with total LEB doses of 25, 50, 75 or 100 kGy. Non-irradiated powder was used as a control. After LEB irradiation, ESR measurement, weight-average molecular weight measurement and three-point bending test were performed.
Results: ESR spectrum of control had no peaks. After LEB irradiation, nine peaks were observed in each ESR spectrum, which indicates the presence of free radicals from main polymer chain. The quantity of free radicals increased linearly up to 100 kGy. Calibrated weight-average molecular weights were as follows: control, 960,000; 25 kGy, 500,000; 50 kGy, 440,000; 75 kGy, 410,000; and 100 kGy, 390,000. Molecular weight decreased with increasing LEB irradiation dose. The mean values of flexural strength (MPa) were as follows: control, 61.5 ± 3.0; 25 kGy, 68.1 ± 4.0; 50 kGy, 73.0 ± 1.9; 75 kGy, 70.4 ± 3.6; and 100 kGy, 67.7 ± 2.3. The flexural strength of the specimens cured with the LEB-irradiated powder was significantly higher than that of control ($p < 0.01$). These results indicate that flexural strength of polymer materials cured with the LEB-irradiated powder increases because of increase in cross-linking structure.
Conclusion: It is confirmed that LEB irradiation onto the polymer powder of self-curing acrylic resin improves the flexural strength.

1. Introduction

Dental acrylic resin is made from a mixture of methylmethacrylate (MMA) and polymethylmethacrylate (PMMA), and has been widely used in dentistry since it was developed in 1937 [1]. At present, there are heat-curing, self-curing and light-curing resins available, and the appropriate type is selected according to the purpose.

Self-curing acrylic resins, which are polymerized by mixing polymer powder and monomer liquid at room temperature, are used in a variety of clinical applications, such as

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1883-1958/$ – see front matter
http://dx.doi.org/10.1016/j.jpor.2013.10.004

fabricating provisional restorations, repairing dentures and adjusting occlusion. However, the chemical and mechanical properties of this resin are inferior to those of heat-curing resin [1–3]. In addition, self-curing acrylic resin often produces fracture of provisional restorations, re-fracture of the repaired denture and early wear of the reconstructed occlusal surface, which causes clinical problems [1,4–7]. Therefore, various techniques have been studied to improve these shortcomings [5–10]. We focused on low-energy electron beam (LEB) irradiation treatment to improve resin properties [11]. In general, electron beam irradiation treatment is used as a post-curing technique for hardening and improving wear resistance of polymer materials [12], and there have been some reports about the mechanical properties of dental acrylic resin being improved by this technique [13–16]. However, the technique has not yet been applied to the dental field because installing electron beam irradiation equipment at individual dental offices is difficult. Therefore, we hypothesized that installation of such irradiation equipment is unnecessary at each dental office, if the mechanical properties of the polymer material are improved by LEB irradiation onto the polymer powder of self-curing acrylic resin prior to polymerization with monomer.

The purpose of this study was to evaluate the effectiveness of LEB irradiation onto the polymer powder for improving the properties of the polymer material by examining whether the characteristics of the powder and the flexural properties of the polymer material changed under various LEB irradiation doses.

2. Materials and methods

2.1. LEB irradiation

LEB irradiation was carried out at 110 kV and 16 μA in a nitrogen atmosphere at room temperature using a low energy electron beam radiation system (EES-S-MJC01; Hamamatsu Photonics K.K. & Meirin College, Hamamatsu, Japan). The test material used was self-curing acrylic resin supplied in polymer powder and monomer liquid form (Unifast III; GC, Tokyo, Japan). The powder was placed into an aluminum dish, which was set on an irradiation stage in the LEB radiation system. The distance between the irradiation window and irradiation stage was 15 mm, and the stage was moved under the window at a speed of 50 mm/s (Fig. 1). Under these conditions, the LEB energy dose was 25 kGy per movement, and the powder was irradiated with total LEB doses of 25, 50, 75 or 100 kGy. Non-irradiated powder was used as a control.

2.2. Electron spin resonance (ESR) measurement

In order to directly detect unpaired electrons and investigate the characteristics of free radicals under different LEB irradiation doses, ESR spectroscopy (JES-RE3X; JEOL, Tokyo, Japan) was used for measurement of powder specimens (0.10 ± 0.01 g) placed in glass tubes 1 h after LEB irradiation at room temperature (Fig. 2). Measurement conditions for acquisition of ESR spectral data were as follows: microwave power, 1 mW; frequency modulation, 100 kHz; amplitude modulation, 9 G; time constant, 0.3 s; and magnetic field range, 326–346 mT.

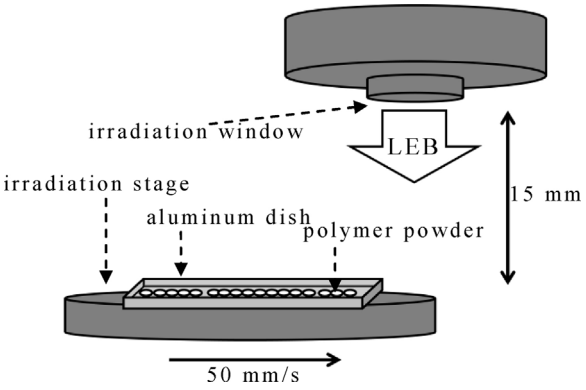

Fig. 1 – Schematic diagram of LEB irradiation. The distance between the irradiation window and the irradiation stage is 15 mm, and the stage is moved under the window at a speed of 50 mm/s.

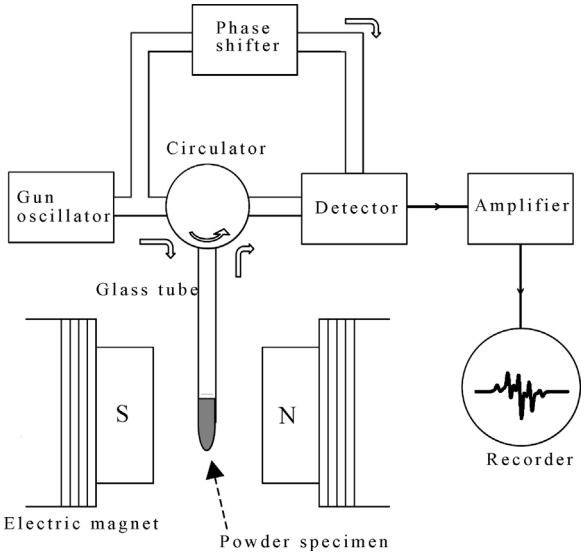

Fig. 2 – Schematic diagram of ESR measurement.

2.3. Measurement of weight-average molecular weight

As the molecular weight of the powder affects polymer characteristics, the weight-average molecular weight of the powder specimens was measured by high performance liquid chromatography (HPLC) (LC-10A; Shimadzu, Tokyo, Japan). Solvent in which the powder was dissolved in tetrahydrofuran at a concentration 0.6% (w/v) was measured using four columns connected to the HPLC system at a flow rate of 0.8 mL/min and a temperature of 40 °C. The obtained HPLC peak for each powder specimen was calibrated with an analytical curve prepared using PMMA of known molecular weight. The weight-average molecular weight was estimated using the software installed in this apparatus.

2.4. Three-point bending test

Self-curing acrylic resin was handled as follows: the powder/liquid ratio (P/L) was 1.3, in accordance with the