Available online at www.sciencedirect.com
ScienceDirect
Acta Biomaterialia 2 (2006) 633–639
Acta BIOMATERIALIA
www.actamat-journals.com

Experimental and computational approach for evaluating the mechanical characteristics of dental composite resins with various filler sizes

Yasuhiro Tanimoto [a,*], Tsuyoshi Kitagawa [b], Masahiro Aida [b], Norihiro Nishiyama [a]

[a] *Department of Dental Biomaterials, Nihon University School of Dentistry at Matsudo, 2-870-1 Sakaecho Nishi, Matsudo, Chiba 271-8587, Japan*
[b] *Department of Crown and Bridge Prosthodontics, Nihon University School of Dentistry at Matsudo, 2-870-1 Sakaecho Nishi, Matsudo, Chiba 271-8587, Japan*

Received 24 April 2006; received in revised form 29 May 2006; accepted 27 June 2006

Abstract

This study aimed to investigate the influence of particle size of fillers on flexural properties of dental composite resins by laboratory testing with computational analysis validation. Four kinds of silica fillers with mean particle sizes of 3.3, 4.3, 7.9, and 15.5 μm were used. Filler content was kept constant at 70 mass% (or 53.8 vol.%). The three-point bending test was performed with a constant loading speed of 1.0 mm/min, and a span length of 20 mm using an Instron machine, in order to measure flexural strength and modulus of composite resins with various particle sizes. Test specimens were 2-mm wide, 2-mm thick, and 25-mm long rectangular bars. Furthermore, a numerical simulation using three-dimensional finite element (FE) analysis was performed to investigate stress distribution in composite resins under loading. As a result, flexural strength decreased with increasing particle size of the filler of the composite resins ($p < 0.05$). On the other hand, there was no significant difference in Young's modulus among composite resins with various filler sizes ($p > 0.05$). Moreover, FE analysis indicated that stress concentration increased with increasing particle size in agreement with experimental results of flexural strength. In conclusion, within the limitations of this investigation, we confirmed that flexural strength of composite resins decreased with increasing filler particle size. In addition, FE analysis was effective for evaluating stress distributions of dental composite resins with various filler sizes.

Keywords: Dental composite resins; Flexural properties; Particle size; Finite element analysis; Stress distribution

1. Introduction

Dental composite resins are commonly used as restorative materials for dental treatments [1]. A dental composite resin is a dispersion-strengthened composite material composed of silica glass and dimethacrylate. In order to enhance bonding between silica and the matrix resin, silica glass is treated with a silane coupling agent, which has a methacryloyl group at its terminal end [2]. The concentration rate of filler is generally 70–80% by weight. The particle size of the filler ranges from 0.04 to 85 μm, and it is well known that the mechanical properties of dental composite resins are controlled by this particle size. Therefore, mechanical properties of dental composite resins such as compressive strength [3], fracture toughness [4], and frictional wear [5] have been studied in relation to the filler particle size. Mitsuhashi et al. [4] reported that the fracture toughness of resin-modified glass ionomer restorative materials increased with increasing powder particle size. Tanimoto and Nemoto [5] demonstrated that the coefficient of friction and wear depth increased with increasing particle size of the filler of composite resins.

* Corresponding author. Tel.: +81 47 360 9349; fax: +81 47 360 9350.
E-mail address: tanimoto.yasuhiro@nihon-u.ac.jp (Y. Tanimoto).

1742-7061/$ - see front matter
doi:10.1016/j.actbio.2006.06.006

The finite element method (FEM) [6] is a powerful and effective tool for analyzing stress distribution of structures in industrial environments. FEM is a theoretical technique in which a complex structure is subdivided into a number of small elements of simple shapes. When deformations of all small elements are simultaneously calculated, total deformation of the overall structure can be reconstructed. For dental applications, FEM is employed to evaluate dental restorations [7,8], fixed partial dentures [9], dental posts [10], dental implants [11], and implant-supported prostheses [12]. For example, de Jager et al. [8] investigated the effects of different core materials on stress distribution in dental crowns using finite element (FE) analysis. Likewise, Fischer et al. [7] evaluated the loading capacity of polymer-based dental bridges reinforced by incorporated ceramic bars using both FE and experimental analyses. They revealed, using FE and experimental analyses, that the detailed design of the ceramic bar was decisive with regard to the effectiveness of the ceramic reinforcement.

We previously investigated the effects of filler content on flexural properties of dental composite resins using FE analysis and experimental analyses [13]. We showed that flexural properties of dental composite resins increased with increasing filler volume content. Additionally, a close agreement between analytical and experimental results was confirmed.

However, no simple approach for determining the effects of filler size on flexural properties of dental composite resins has been reported.

The aim of the present study was to examine the effects of filler size on flexural properties of dental composite resins from experimental and analytical points of view.

2. Materials and methods

2.1. Materials

A base monomer consisting of 60 mol% urethane dimethacrylate (UDMA, Negami Chem. Ind. Co. Ltd., Ishikawa, Japan) and 40 mol% triethyleneglycol dimethacrylate (TEGDMA, Shin-Nakamura Chem. Co. Ltd., Wakayama, Japan) was used as the matrix resin. A light-cured resin was designed by dissolving into the base monomer 1 mass% of camphorquinone (CQ, Aldrich Chem. Co. Inc., Milwaukee, USA) and 0.5 mass% of dimethylaminoethyl methacrylate (DMAEMA, Wako Pure Chem. Ind. Ltd., Osaka, Japan). Silica fillers used as reinforcements in this study are listed in Table 1. All types of spherical silica particles were produced by Tatsumori Ltd., Tokyo, Japan. Four kinds of silica fillers with mean particle sizes of 3.3, 4.3, 7.9, and 15.5 μm were used in this study. The coupling agent was γ-methacryloxy propyltrimethoxysilane (γ-MPTS, Shin-Etsu Corp., Tokyo, Japan). The silica filler was treated with 2 mass% of a γ-MPTS solution consisting of 70 mass% ethanol and 30 mass% water. The silane-treated silica was then dried at room temperature for 24 h. To obtain the composite resin, fillers treated with γ-MPTS were added at 70 mass% (53.8 vol.%) to the base monomer.

Table 1
Silica fillers used in this study

Product name	Particle size (μm)	Batch No.
PLV-4	3.3	20502
PLV-6	4.3	10403
TB-8	7.9	H2811
TB-15	15.5	030101

2.2. Preparation of specimens

To prepare three-point bending test specimens, the composite resin paste was placed between two glass slides, between which a 2.1-mm spacer had been placed. The surface of the composite resin was covered with polyester strips (Striproll, KerrHawe, Bioggio, Switzerland). The molded composite resin was then pressed between the slides. Visible light was radiated to both surfaces using α-LIGHT II (J. Morita Tokyo Mfg. Corp., Tokyo, Japan) for 90 s. Following polymerization, the composite resin was carefully removed from the mold. Both surfaces of the composite resin were polished using 800- and 1000-grit SiC papers. The specimens for the bending test were 2-mm wide, 2-mm thick, and 25-mm long rectangular bars.

In addition to these four specimens, a matrix resin specimen was also prepared to determine the material properties to be used for the FE analysis.

2.3. Three-point bending test

Three-point bending tests were performed with a constant loading speed of 1.0 mm/min, and at a span length of 20 mm using a computer-controlled INSTRON testing machine (TCM500CR, Minebea, Tokyo, Japan). Flexural strength F and Young's modulus E were calculated using the following formula:

$$F = (3/2)(PL/bh^2) \quad (1)$$

$$E = (1/4)(L^3/bh^3)k \quad (2)$$

where P represents the maximum load defined as the yield load of the material, L is the span length, b is the specimen width, h is the specimen thickness, and k is the slope at the initial stage in the load–deflection curve. Experimental results represented averages of five measurements ($n = 5$).

2.4. Statistical analysis

Data were examined with analysis of variance (ANOVA), and were tested using Scheffé multiple comparisons test among means with a significant p value set at <0.05.

ID	Title	Pages
2629	Experimental and computational approach for evaluating the mechanical characteristics of dental composite resins with various filler sizes	7