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Original article

Glass fiber-reinforced thermoplastics for use in metal-free removable partial dentures: combined effects of fiber loading and pigmentation on color differences and flexural properties

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ABSTRACT

Purpose: The purpose of this study was to investigate the combined effects of fiber loading and pigmentation on the color differences and flexural properties of glass fiber-reinforced thermoplastics (GFRTPs), for use in non-metal clasp dentures (NMCDs).
Methods: The GFRTPs consisted mainly of E-glass fibers, a polypropylene matrix, and a coloring pigment: the GFRTPs with various fiber loadings (0, 10, and 20 mass%) and pigmentations (0, 1, 2, and 4 mass%) were fabricated by using an injection molding. The color differences of GFRTPs were measured based on the Commission Internationale de l'Eclairage (CIE) Lab color system, by comparing with a commercially available NMCD. The flexural properties of GFRTPs were evaluated by using a three-point bending test, according to International Standards Organization (ISO) specification number 20795-1.
Results: The visible colors of GFRTPs with pigment contents of 2 mass% were acceptable for gingival color, and the glass fibers harmonized well with the resins. The ΔE^* values of the GFRTPs with pigment contents of 2 mass% obtained by using the CIE Lab system were lowest at all fiber loadings. For GFRTPs with fiber contents of 10 and 20 mass% at 2 mass% pigment content, these GFRTPs surpassed the ISO 20795-1 specification regarding flexural strength ($>$ 60 MPa) and modulus ($>$ 1.5 GPa).
Conclusions: A combination of the results of color difference evaluation and mechanical examination indicates that the GFRTPs with fiber contents of 10 or 20 mass%, and with pigment contents of 2 mass% have acceptable esthetic appearance and sufficient rigidity for NMCDs.

1. Introduction

Metal clasps are commonly used as a part of the assembly for removable partial dentures (RPDs). However, the metallic alloys used for such metal clasps are unesthetic and have the potential to cause allergic reactions [1]. In response to patients' demands for good esthetic appearance and metal-free restoration, injection-molded thermoplastic resins such as polyamides, polyesters, polycarbonates, and polypropylenes have been used in non-metal clasp dentures (NMCDs), which do not have visible metal clasps [2]. The NMCDs made by using thermoplastic resins are much more esthetically pleasing than conventional RPDs with metal clasps, and their excellent esthetic appearance meets the demands of patients [3].

Although such esthetic considerations are critical, denture stability is clinically important for restoring oral function in prosthodontic treatment with RPDs [4,5]. The mechanical properties such as the flexural strengths and moduli of NMCDs are inferior to those of conventional poly(methyl methacrylate) (PMMA) dentures [1,6]. Accordingly, the use of NMCDs without metal elements may have serious disadvantages such as resorption of the residual ridge under the denture base because the NMCDs cannot prevent deformations caused by occlusal force [7,8].

To address this issue, in a previous study, glass fiber-reinforced thermoplastics (GFRTPs) made from E-glass fibers and polypropylene for use in NMCDs were developed by using an injection-molding method [6]. The previous study examined the effects of the fiber content, from 0 to 50 mass%, on the physical and mechanical properties of GFRTPs. The results showed that the properties of these materials can be tailored by varying their fiber contents. GFRTPs with fiber contents of 10 and 20 mass% had sufficient rigidity, similar to that of PMMA dentures, and their flexibilities were similar to those of available NMCDs. The findings suggest that these GFRTPs can be used in NMCDs because their excellent mechanical properties give both sufficient rigidity and elasticity.

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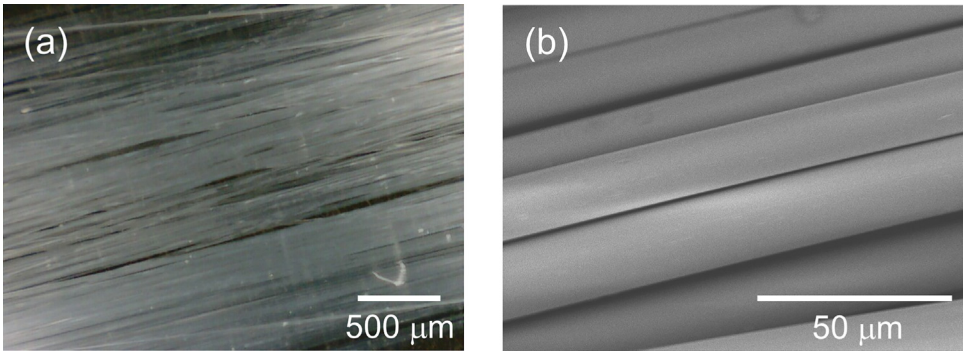

Fig. 1. Appearances of glass fibers contained in GFRTP pellet as reinforcement. (a) Microscopic color image of glass fibers used for reinforcement (original magnification: 100×). Glass fibers were prepared by burning out GFRTP pellet at 650 °C in an electric furnace. (b) Field-emission scanning electron microscopy (FE-SEM) image of glass fibers (original magnification: 1000×). Fiber diameter is –17 μm.

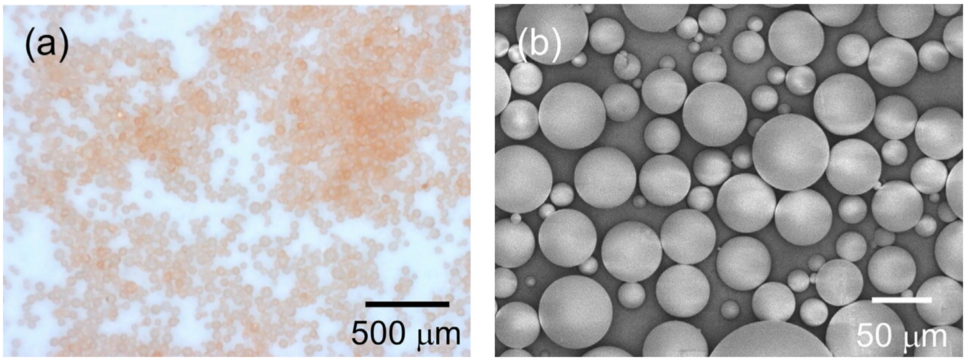

Fig. 2. Appearances of PMMA particles as pigment. (a) Microscopic color image of PMMA particles used as pigment (original magnification: 100×). PMMA particles were coated with minimal quantity of Fe_2O_3 to give human gingiva color. (b) FE-SEM image of pigment (original magnification: 300×). Pigment particle size is –30 μm.

In addition to having appropriate mechanical properties, the GFRTP color must match that of the patient's oral tissue because uncolored GFRTPs are translucent. The PMMA resins that are extensively used for denture bases mimic the color of the gingiva to provide an acceptable appearance [9]. Carbon black, zinc oxide, titanium dioxide (TiO_2), and iron oxide (Fe_2O_3) are incorporated into PMMA resins to create a customized natural color for the patient before polymerization. Goiato et al. [9] reported that TiO_2 pigmentation improved the color stability of PMMA. Silva et al. [10] investigated the effects of acrylic stain concentrations of 0.5 and 1.5 mass% on the flexural strength. The authors concluded that the addition of acrylic stain to PMMA did not affect its flexural strength and that pigmentation gave esthetically acceptable results for clinical use. As in the case of PMMA, commercially available NMCD materials also mimic the gingival color; however, there has been no investigation of the effects of pigmentation on their esthetic and physical properties. The effect of GFRTP pigmentation is a critical factor in ensuring the success of these dental prostheses and the oral health of patients.

In this study, GFRTPs with fiber contents of 0, 10, and 20 percent by weight (mass%) were prepared as described in a previous study of the optimum fiber content for GFRTPs [6]. Acrylic-based red pigments were incorporated into the GFRTPs to match their color to that of the patient's gingiva; staining with pigments at concentrations of 0, 1, 2, and 4 mass% were assessed. The purpose of this study was to assess the combined effects of fiber loading and pigmentation on the color differences and mechanical properties of GFRTPs for use in NMCDs. The first hypothesis was that color differences of GFRTPs would be influenced by fiber loading and pigmentation; the second hypothesis was that flexural properties of GFRTPs would be influenced by fiber loading and pigmentation. The materials developed in this study will provide reliable NMCD materials that meet the demands of both patients and dentists.

2. Materials and methods

2.1. Sample preparation

GFRTP pellets (Plastron PP-GF50-02; Daicel Polymer, Tokyo, Japan) consisting of polypropylene reinforced with E-glass fibers were used. The glass fibers in the GFRTP pellet were of diameter of 17 μm and length 10 mm (Fig. 1). The GFRTP pellets were diluted with unreinforced polypropylene pellets (Daicel Polymer) to produce GFRTPs with various fiber contents (0, 10, and 20 mass %). GFRTPs with fiber contents of 0, 10, and 20 mass% are denoted by GF0, GF10, and GF20, respectively.

Commercially available red pigments (Aesthetic Intensive-Colors Purpur Red; Candulor, Glattpark, Switzerland), which are shown in Fig. 2, were prepared and used to match the GFRTP color to that of human gingiva. The effects of pigmentation on the characteristics of the fabricated GFRTPs were investigated by adding pigments at four contents, namely 0, 1, 2, and 4 mass%, relative to the amount of GFRTP mixture (i.e., GFRTP pellets and polypropylene pellets), to the initial GFRTP mixtures. The GFRTP mixtures were melted and mixed in a conventional melt-mixer at 250 °C for 12 min. The GFRTP mixtures were injection-molded into gypsum molds with cavities (65 mm long, 32 mm wide, 3.3 mm high) by using an injection-molding system (MH-01; Unival, Tokyo, Japan). The injected-molded assembly was cooled to room temperature in an ambient atmosphere and then the GFRTP plate was carefully removed from the mold. The specimens used for three-point bending tests according to the International Standards

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