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Reinforcement of denture base resin with short vegetable fiber

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ABSTRACT

Objectives. Short ramie fibers were selected to investigate the effect of fiber length and volume fraction on the flexural properties of ramie fiber reinforced denture base PMMA. With the aid of measured interfacial shear strength and theoretical prediction values, experimental results were well interpreted.

Methods. Interfacial properties between denture base PMMA and ramie fibers were evaluated by single fiber pull-out test. Then, chopped ramie fibers were pre-stirred with PMMA powder by a mechanical blender and then mixed with MMA liquid to fabricate composites. Two crucial influencing factors, fiber volume fraction and fiber length, were studied to clarify their effects on flexural properties of composites.

Results. With 1.5 mm fibers addition, flexural modulus of denture base PMMA rose from 2.50 to 3.46 GPa with 10 vol.% fibers, while flexural strength declined steadily with increment of fiber content. If fiber length was 3.0 mm, the modulus showed a growth to 3.5 GPa at 4 vol.% fiber content followed by a drop to 3.00 GPa at 10 vol.%, whereas fluctuation in strength was experienced. Experimental results were discussed by comparison with two theoretical models.

Significance. Short ramie fiber reinforced denture base PMMA had higher flexural modulus than neat resin, while strength was lowered due to the weak interfacial adhesion. The potential of vegetable fibers as reinforcing agents for denture base should be further investigated by strengthening the interface between cellulose and denture base PMMA.

1. Introduction

Reinforcing fibers were introduced to the family of denture base materials, in order to fulfill their requirement on higher mechanical properties against occlusal overload. Among the wide varieties of used reinforcing agents, glass fibers [1–5] and several kinds of polymeric fibers, e.g. ultra-high molecular weight polyethylene fiber (UHMWPE) [6,7], have attracted more attentions due to their high tensile properties and acceptable esthetic appearance. However, when fiber came out from the surface of the resin as a result of degradation of resin or mechanical failure, clinical problems such as mucosal irritation might happen [8,9]. Thus, not only reinforcing capacity but also clinical applicability of fibers should be considered during selections. As a result of this fact,

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Table 1 – Chemical composition of ramie fiber [16].

Component	Percentage by mass
Cellulose	67–99
Hemicellulose	13–14
Pectin	1.9–2.1
Lignin	0.5–1.0
Fat/wax	0.3

Table 2 – Physical and mechanical properties of ramie fiber.

Property	Value[a]
Density (g/cm^3)	1.50
Tensile strength (MPa)	310
Tensile modulus (GPa)	61.4–128 [17]
Fractural elongation (%)	3.0

Tensile modulus was referred.
[a] From laboratorial tests, averaged in normal distribution.

investigations on the potential of alternative reinforcing agents were ongoing.

In the range of naturally obtainable fibers, vegetable fiber is one of the promising biomaterials due to its biocompatibility [10–13]. More importantly, they occupy much higher Young's modulus and ultimate tensile strength than denture base resin. Therefore, these two inherent properties of vegetable fibers make it worthwhile to characterize their potential as new reinforcing agents for denture base. To authors' best knowledge, Kondo et al. [14] first introduced short sisal fiber to denture base PMMA. Their results showed that with the increment of fiber content, flexural modulus of composites showed a slight growth at 2.5 wt% and then a continuous decline up to 10 wt%, whereas flexural strength decreased apparently and fluctuated versus fiber content. On top of this, they suggested that further studies should regard fiber aspect ratio and surface treatment.

Ramie is one of the oldest textile fibers known as "china grass", which are referred as bast fibers and come from the phloem tissue of the plant [15]. It has significantly smaller diameter (10–60 μm) and consequently higher aspect ratio than sisal fiber (200–300 μm) at the same length. In addition, its whiteness might also fulfill the requirement of denture base on esthetical appearance. Due to these facts, the present work aimed to investigate the potential of ramie fiber as a reinforcing agent for denture base resin. In order to disperse short ramie fiber homogeneously in high-viscous denture base PMMA, the approach of mechanical stirring was applied during the fabricating stage. Specifically, effects of fiber volume content and length as well as dispersion and interfacial property on flexural properties of composites were detailedly discussed.

2. Materials and methods

2.1. *Materials*

Heat-polymerizing denture base materials (Rapid Simplified®) were purchased from Vertex Dental, Netherlands and ramie fibers from Hunan province, China. Chemical composition, physical and mechanical properties of ramie fibers were listed in Tables 1 and 2, respectively.

Long ramie fibers were pre-impregnated in 5 wt% sodium hydroxide solution, in order to remove wax and other impurities from ramie fiber [18], which was followed by washing and then drying to drive out residual waters. 100 samples of mercerized ramie fibers were randomly selected and their diameters were measured with the aid of an optical microscope.

2.2. *Fabrication of single fiber pull-out specimens*

In order to insure the single fiber located centrally through-thickness direction of the resin, two pieces of plastics with rectangular grooves were cut off from the same plate. Afterwards plastic mold and ramie fibers were positioned with double-sided adhesive tape onto a stainless steel plate, then mixed resin were injected into the overlapped groove with a syringe. When the resin reached dough stage, plastic mold was covered with another stainless steel plate and then pressed under 1 MPa and heated at 100 degrees for 20 min, according to manufacturer's instruction of curing denture base PMMA. After demolding, specimens for single fiber pull-out test were chopped carefully from the groove and 31 samples with matrix in regular shape were obtained out of 40. Finally, diameters of fibers and their embedded lengths in the matrix were measured with an optical microscope.

2.3. *Fabrication of short fiber reinforced composites*

Mercerized ramie fibers were carefully chopped with a scissor, desiring to the length of 1.5 and 3.0 mm. 100 samples for both lengths were randomly selected and measured with a vernier caliper. The majority for the former proved to be 1.5 ± 0.1 mm and for the latter 3.0 ± 0.2 mm.

Each group was divided into 4 sub-groups of different weight. Then they were mixed with PMMA powder and stirred with a blender at a rotating speed of 400 rpm (Fig. 1). After 5 min, fibers randomly oriented in PMMA powder and MMA was afterwards added to their mixture at a ratio of 0.6 ml/g (liquid: powder). When the resin reached dough stage, it was poured into a mold and hot-pressed under the same pressure and temperature as in Section 2.2. After demolding, no visibly seen bubbles existed in the composites by making the samples following the manufacturer's (Vertex Dental) instruction. Then, weight fractions of fiber in composites were calculated into volume fractions.

2.4. *Mechanical testing*

Single fiber pull-out test was conducted at a crosshead speed of 1 mm/min based on ASTM STP 452. According to ASTM D7264, specimens for flexural test were cut from molded composites to the dimension of 64 mm × 12.7 mm × 3 mm and the crosshead speed was also 1 mm/min.