DENTAL MATERIALS 34 (2018) 598–606

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

Mechanical properties and fracture behavior of flowable fiber reinforced composite restorations

Lippo Lassila[a,b], *Filip Keulemans*[a], *Eija Säilynoja*[c], *Pekka K. Vallittu*[a,b,d], *Sufyan Garoushi*[a,b,*]

[a] *Department of Biomaterials Science, Institute of Dentistry, University of Turku, Finland*
[b] *Turku Clinical Biomaterial Center—TCBC, Institute of Dentistry, University of Turku, Turku, Finland*
[c] *Research Development and Production Department, Stick Tech Ltd—Member of GC Group, Turku, Finland*
[d] *City of Turku Welfare Division, Oral Health Care, Turku, Finland*

ARTICLE INFO

Article history:
Received 30 August 2017
Received in revised form
18 November 2017
Accepted 8 January 2018

Keywords:
Fiber reinforced flowable composite
Fracture toughness
Posterior restoration

ABSTRACT

Objective. The aim was to evaluate the effect of short glass-fiber/filler particles proportion on fracture toughness (FT) and flexural strength (FS) of an experimental flowable fiber-reinforced composite (Exp-SFRC) with two methacrylate resin formulations. In addition, we wanted to investigate how the fracture-behavior of composite restorations affected by FT values of SFRC-substructure.

Methods. Exp-SFRC was prepared by mixing 50 wt% of dimethacrylate based resin matrix (bisGMA or UDMA based) to 50 wt% of various weight fractions of glass-fiber/particulate filler (0:50, 10:40, 20:30, 30:20, 40:10, 50:0 wt%, respectively). FT and FS were determined for each experimental material following standards. Specimens ($n = 8$) were dry stored (37 °C for 2 days) before they were tested. Four groups of posterior composite crowns ($n = 6$) composed of different Exp-SFRCs as substructure and surface layer of commercial particulate filler composite were fabricated. Crowns were statically loaded until fracture. Failure modes were visually examined. The results were statistically analysed using ANOVA followed by post hoc Tukey's test.

Results. ANOVA revealed that ratio of glass-fiber/particulate filler had significant effect ($p < 0.05$) on tested mechanical properties of the Exp-SFRC with both monomer systems. Exp-SFRC (50 wt%) had significantly higher FT (2.6 $MPam^{1/2}$) and FS (175.5 MPa) ($p < 0.05$) compared to non-reinforced material (1.3 $MPam^{1/2}$, 123 MPa). Failure mode analysis of crown restorations revealed that FT value of the substructure directly influenced the failure mode.

Significance. This study shows that short glass-fibers can significantly reinforce flowable composite resin and the FT value of SFRC-substructure has prior importance, as it influences the crack arresting mechanism.

* *Corresponding author at*: Department of Biomaterials Science, Institute of Dentistry and TCBC, University of Turku, Turku, Finland.
E-mail address: sufgar@utu.fi (S. Garoushi).

https://doi.org/10.1016/j.dental.2018.01.002
0109-5641/

1. Introduction

Today, particulate filler composite resins (PFCs) are selected on a regular basis for direct and laboratory made posterior restorations, as an extension to their original indication, which was limited to direct restorations in anterior teeth. Their use has been widened not only to the posterior intracoronal area, but also to extra-coronal restorations [1]. In addition, composite resins came into focus for the fabrication of resin-bonded fixed dental prostheses (RBFDP) after the introduction of fiber-reinforced composites (FRC). However, insufficient material properties limited the success of composite restorations in high stress bearing areas [2,3]. Fracture within the body (bulk) and margins of restorations and secondary caries have been cited as major problems regarding the failure of posterior composites [4]. The fracture related material properties, such as fracture resistance, deformation under occlusal load, and the marginal degradation of materials have usually been evaluated by the determination of the basic material parameters of flexural strength and fracture toughness [5]. Fracture toughness is a mechanical property that describes the resistance of brittle materials to the catastrophic propagation of flaws under an applied load, and thus, it describes damage tolerance of the material and can be seen as a measure of fatigue resistance. Fracture toughness values are dependent on the physical properties and chemical composition of the individual component of restorative material. From a biomimetic point of view, we strive to replace lost tooth tissue by biomaterials with similar physical properties, especially with reference to flexural strength, modulus and thermal expansion coefficient [6]. A generally accepted biomimetic restorative approach advocates replacing enamel with feldspathic porcelain or glass ceramic and dentine by hybrid composites [6,7]. Although such approach seems effective there are still relevant mechanical properties, such as fracture toughness, not taken into account. Fracture toughness of hybrid PFC is significantly lower than that of dentine [8]. Furthermore, the microstructure of hybrid composite does not match that of dentine. Hybrid PFC consists of filler particles embedded in a resin matrix while dentine consists of collagen fibers embedded in a hydroxyapatite matrix. Therefore dentine should be rather seen as a fiber-reinforced composite instead of a particulate filler composite. For that reason improvement could be found when taking advantage of a more dentine-like and high toughness composite as dentine replacement. A material which has high fracture toughness has the ability to better resist crack initiation and propagation. Consequently, the property of fracture toughness and flexural strength become important criterions in a dental materials' longevity [9,10].

Till now, composite resins reinforced with millimetre scale short glass fibres (SFRC) are the most interesting materials because of their close resemblance to dentine at the level of microstructure and mechanical properties [11–14]. This composite was previously reported to exhibit improved mechanical properties regarding strength, fracture toughness, fatigue resistance and polymerisation shrinkage and to show a more favorable (repairable) type of failure behavior in comparison to particulate filler composite [15–17]. The discontinuous fibers lengths for the SFRC were measured between 0.3 mm and 1.9 mm, which makes the lowest aspect ratio 18 and greatest 112 [18].

Many of the properties of fiber composites are strongly dependent on microstructural parameters such as resin matrix, fiber diameter, fiber length, fiber orientation and fiber loading [18,19]. The intent of this study was to evaluate the effect of microfibers loading and resin matrix type on the mechanical properties of flowable dental resin composite. To the authorś knowledge, very little research exists in this field. Thus, the hypothesis evaluated was that a flowable dental composite may be significantly reinforced by incorporating randomly distributed microfibers, i.e. fibers of smaller diameter and length than those used in the SFRC which is available commercially (everX Posterior). Further it was hypothesized that, fracture behavior of biomimetic composite restorations can be affected by fracture toughness values of SFRC substructure (core material).

2. Materials and methods

2.1. Materials

Bisphenol-A-glycidyl dimethacrylate (bis-GMA), triethylene glycol dimethacrylate (TEGDMA), and polymethylmethacrylate (PMMA) were purchased from Esstech Inc. (Essington, PA, USA). Diurethane dimethacrylate (UDMA), camphoroquinone (CQ), and *N*,*N*′-dimethyl aminoethyl methacrylate (DMAEMA) were obtained from Sigma-Aldrich Co. (St Louis, MO, USA). Silaned (γ-methacryloxypropyl-tri-methoxy-silane) $BaAlSiO_2$ filler particles were received from Schott (UltraFine GM27884, Schott, Landshut, Germany). All of reagents were used without purification.

2.2. Production of flowable fiber reinforced composite

Experimental flowable short fiber reinforced composite (Exp-SFRC) was prepared by mixing 50 wt% of dimethacrylate based resin matrix (bisGMA/TEGDMA = 60/40 or UDMA/PMMA = 80/20 wt/wt respectively, with 0.7 wt% CQ and 0.7 wt% DMAEMA as a photoinitiator system) to 50 wt% of various weight fractions of glass fiber/particulate filler (0:50, 10:40, 20:30, 30:20, 40:10, 50:0 wt%, respectively) (Table 1). The discontinuous E-glass fibers (as-received silanized) having length scale of 200–300 μm (Ø6 μm), so-called microfibers and silaned $BaAlSiO_2$ filler particles (Ø7 μm) were added gradually to the resin matrix. The average aspect ratio of fibers was 41. The mixing was carried out by using a high speed mixing machine for 2 min (Hauschild Speed Mixer DAC 400.1, 3500 rpm). Temperatures during the mixing were monitored by an infrared thermometer.

2.3. Flexural strength

Three-point bending test specimens ($2 \times 2 \times 25\,mm^3$) were made from each tested composite. Bar-shaped specimens were made in a half-split stainless steel mold between transparent Mylar sheets. Polymerization of the composite was done using a hand light-curing unit (Elipar S10, 3M ESPE,