Tribology International 102 (2016) 361–370

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Tribological behaviour of glass-ceramics reinforced by Yttria Stabilized Zirconia

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ARTICLE INFO

Article history:
Received 21 January 2016
Received in revised form
26 May 2016
Accepted 30 May 2016
Available online 2 June 2016

Keywords:
Glass-ceramic
Zirconia
Composite
Wear

ABSTRACT

The aim of this study was to evaluate the tribological behaviour of a dental glass-ceramic (GC) reinforced by 20% (vol.) Yttria-Stabilized Zirconia. Two types of particles were tested: zirconia agglomerates (ZA) and pre-sintered zirconia particles (ZP). The wear tests were carried out using a ball-on-plate configuration. The wear mechanisms were characterized by field emission guns scanning electron microscope. Results revealed an improvement of wear behaviour for GC reinforced by ZP. The improvement on wear resistance was attributed to the effect of reinforcement, by the action of the uniformly distributed ZP that allowed the load transfer reinforcing mechanism through the matrix and reinforcement phase. Dental glass-ceramic reinforced by ZP can constitute a promising alternative to conventional glass-ceramics to produce prosthetic restorations.

1. Introduction

All-ceramic restorations have been considered a good alternative to overcome the tribocorrosion processes occurring on metal-based materials. Ceramic veneers are used for prosthetic restorative materials based on optical properties which provide proper aesthetic results [1–5]. Despite of aesthetical and biocompatibility improvements over metal-ceramic systems, the main problems reported by in vivo and in vitro studies regarding all-ceramic restorations are poor mechanical properties (low tensile strength, low fracture toughness) and brittleness [2,6–16]. Any small defect in a dental glass-ceramic might represent a stress concentration point from where a crack can propagate, leading to fracture. It has been shown that failure o dental prosthesis implies crack propagation towards the interface [13,15,16].

Nowadays zirconia is one of the best choices for dental restorations due to their mechanical and corrosion properties [17–20]. Yttria-stabilized tetragonal zirconia policristal (Y-TZP) has been used to produce dental prosthetic infrastructures, due to its high mechanical strength, increased fracture toughness, good thermal expansion coefficient, good oxidation resistance and low thermal conductivity, good biocompatibility, low radioactivity, tooth like optical properties [17,18,21–23]. The mechanical properties of Y-TZP are superior to any other ceramic materials. For example, it has been reported that in-vitro flexural strengths range from 900–1200 MPa and the fracture toughness ranges from 9–20 MPa [21–24]. Wang et al. reported that the friction and wear performances of zirconia can be improved significantly by adequate surface polishing [25]. The main problems reported regarding the use of zirconia in dental application are: (i) lack of transparences [26] and (ii) it wears the opposite tooth or restorations [18,24,27,28].

In order to use glass-ceramics in load-bearing applications, it is necessary to enhance their mechanical, fatigue and wear properties. Thus, the addition of a second high-strength biocompatible phase into the glass-ceramic matrix can optimize the properties of the resultant material [29–46]. Glass-ceramics have been reinforced by alumina or zirconia (e.g. Yttria-Stabilized Zirconia) to

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http://dx.doi.org/10.1016/j.triboint.2016.05.047
0301-679X/

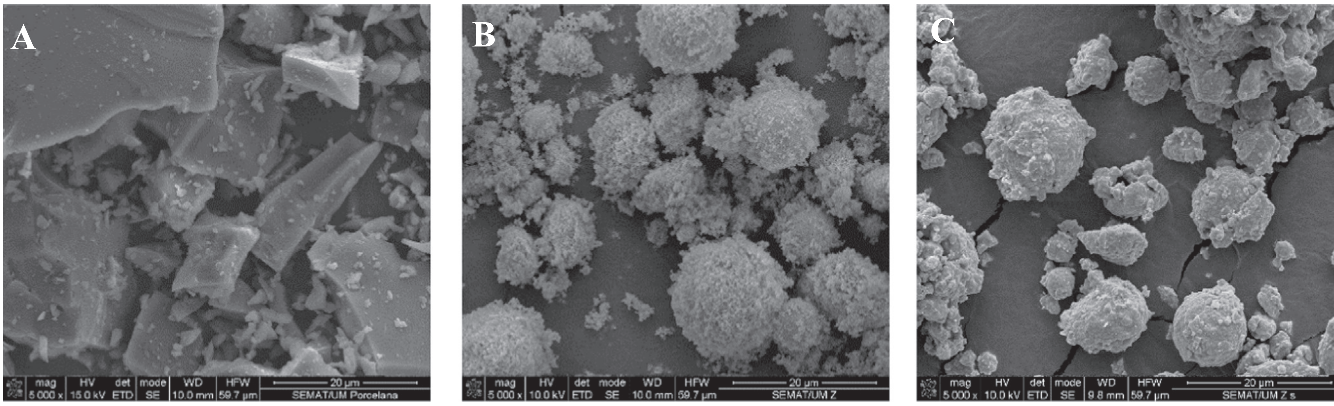

Fig. 1. FEGSEM images showing: A) glass-ceramic; B) zirconia agglomerates; and C) pre-sintered zirconia powders.

Table 1
Chemical composition of dental glass-ceramic powder (wt%).

SiO_2	Al_2O_3	B_2O_3	K_2O	Na_2O	Other oxides
60–64	13–15	3–5	7–10	4–6	~2

Table 2
Chemical composition of 3Y-TZP powder (wt%).

$ZrO_2+HfO_2+Y_2O_3+Al_2O_3$	Y_2O_3	Al_2O_3	HfO_2	Other oxides
99.9	5.2 ± 0.2	<0.4	<0.5	<0.5

improve mechanical properties, fracture toughness, wear resistance, optical properties and biocompatibility and thus to increase their lifespan [35–48].

Guazzato et al. [49] reported that the zirconia reinforced glass-ceramic composites are stronger and tougher materials than the conventional glass-ceramics. Guo [41] reported that there are two factors that may contribute to increase of fracture toughness: "bridging" mechanism and the stress-induced phase transformation of zirconia [50]. The improvement on the properties of the zirconia reinforced glass-ceramic composites was attributed to phase transformation from tetragonal to monoclinic and to the relationship between the glassy matrix and the crystalline second phase in the strengthening and toughening mechanisms of these ceramics. The strengthening mechanisms of zirconia reinforced glass-ceramic composites are based on stopping, deflection or bridging the crack propagation [41,49,51–55]; either, on compressive residual stresses due to thermal mismatch between the glass-ceramic matrix and inorganic fillers. It has been mentioned that the optimization of the microstructure is an important factor for improvement on friction and wear behavior of dental glass-ceramic [47,56]. As stated by He et al. [47], the amount of tetragonal zirconia transformed to the monoclinic crystal structure increased with increasing grain size resulting in a decrease in wear resistance. The volume increment caused by this phase transformation weakens the grain boundaries which results in grain pull-out and delamination [57,58].

The present study reveals the wear behavior of zirconia reinforced glass-ceramic composites in a saliva artificial solution. It was hypothesized that the addition of pre-sintered Yttria-Stabilized Zirconia particles into glass-ceramic is very effective in reducing the wear loss of the resulting material.

2. Experimental procedure

2.1. Materials

A dental glass-ceramic powder (Vita VM9, Vita, Germany) was used as matrix material. The chemical composition of the glass-ceramic is shown in Table 1. FEGSEM images of dental glass-ceramic powder (raw material) as provided by the supplier are shown in Fig. 1A. The powder size distribution of glass-ceramic powder was $D_{10}=2.49$ µm; $D_{50}=18.92$ µm; $D_{90}=50.71$ µm and $D_{ave}=23.47$ µm.

Yttria-Stabilized Zirconia particles – 3Y-TZP (Innovnano, Portugal), were used as reinforcement (Table 2). FEGSEM images of the zirconia agglomerates and pre-sintered zirconia powder are shown in Fig. 1B and C, respectively. The powder size distribution of pre-sintered zirconia is $D_{10}=14.54$ µm; $D_{50}=162.64$ µm; $D_{90}=336.71$ µm and $D_{ave}=166.44$ µm.

2.2. Fabrication of zirconia reinforced glass-ceramic composites

The glass-ceramic was used as matrix material (named as GC from now on).

Two types of zirconia reinforced glass-ceramic composites were produced:

(i) glass-ceramic reinforced by 20% (vol%) Yttria-Stabilized Zirconia (ZrO_2 – 3%Y_2O_3) agglomerates (named as GC/ZA from now on). The 3Y-TZP agglomerates were used as provided by the supplier and blended with the glass-ceramic powders in rotation machine during 24 h.
(ii) glass-ceramic reinforced by 20% (vol%) pre-sintered Yttria-Stabilized Zirconia (ZrO_2–3%Y_2O_3) particles (named as GC/ZP from now on). The 3Y-TZP agglomerates as provided by the supplier were sintered in a furnace at 1500 °C for 2 h. Afterwards, powder mixtures (glass-ceramic and sintered 3Y-TZP), were ball milled to reduce agglomeration and to enhance mixing.

All the samples were processed by the hot pressing (HP) technique [59–64]. Applied pressure was 7 MPa for 2 min at 970 °C under vacuum (1 bar).

2.3. Wear tests

Square test samples (10 × 10 × 2 mm) were embedded in epoxy resin. Samples were wet ground on SiC sandpapers down to 4000 Mesh and then polished using diamond paste (1 µm). Samples were ultrasonically cleaned in isopropyl alcohol for 15 min and then in distilled water for 15 min. A reciprocating ball-on-plate tribometer (Bruker-UMT-2) was used to evaluate the wear of square samples (10 × 10 × 2 mm) against Al_2O_3 counterbody