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Effect of Al_2O_3 on leucite based bioactive glass ceramic composite for dental veneering

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Abstract

A wide variety of dental ceramic composites have been introduced in the restorative dentistry in order to associate the desired aesthetics and superior mechanical performance. Mechanochemically derived leucite based bioactive glass ceramic composites have been prepared and studied by their thermal, crystal structure, microstructural, mechanical and biological behavior. In the prepared glass-ceramic composites, fine alumina has been added to improve their mechanical properties because it has biocompatibility, high hardness and good mechanical strength. Flexural strength and coefficient of thermal expansion (CTE) have been studied and the results are compared to the commercial dentine. Alumina added glass ceramic composites show high flexural strength than that of the pure leucite based glass ceramic composite. A second phase nepheline has been formed in the alumina added samples. Nepheline has high CTE. This causes a slight increase in the CTE of the whole matrix. Micrographs show the complete attachment and proliferation of the SSC-25 cells on the surface of the samples. This confirms the bioactive behavior of the prepared composites. Therefore, it is concluded that the addition of alumina to the glass ceramic composite is a successful approach to improve its mechanical and biological properties.

Keywords: A. Milling; B. Composites; C. Thermal expansion; D. Glass ceramics; E. Alumina

1. Introduction

Ceramic materials used in restorative dentistry have specific properties such as durability in the oral environment, similarity with natural tooth structure, high wear resistance and mechanical strength [1–3]. Metal ceramic restorations (MCR) are commonly used due to their good fracture resistance [4]. These consist of metal substructure and several layers of dental porcelain [5]. Feldspathic porcelains consists of glassy aluminosilicate and crystalline leucite is mostly used for MCR [6–8]. Leucite is a precious phase in the dental ceramic restorations. It increases the thermal expansion of dental ceramics and results in a good bonding to the metal framework [9]. Problems occur with the patient is associated with the failure of fixed MCR due to secondary carries [10–12]. This resulted in a plaque accumulation in the marginal area between the fixed tooth and restoration. This causes the bacterial attack leading to pulp irritation and the dissolution of the luting cement [13]. A hypothetical tissue attachment on the margins of a restoration would eliminate the marginal gap, cement dissolution and subsequently the secondary caries. Cells no more adhere to the damaged tooth structure after preparation of a tooth for a restoration. The marginal gap is unavoidable in dentistry but it could be decreased or filled by precipitation of hydroxyapatite by using the developed ceramic composites in only marginal areas of restorations. As well as for different purposes in implant custom ceramic abutments at collar or emerging profile regions.

Dental ceramic materials are bio-inert and unable to interact with the surrounding tissues [1,14]. According to L. L. Hench, a bioactive glass prompts a specific biological response at the interface of the hard tissue and the material [15,16].

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A hydroxyapatite (HAp) layer is formed which enhances the cell proliferation and the cell attachment, thereby sealing the marginal gap [17–21]. Over the last few years, research has been carried on the development of apatite layer on dental ceramics by adding the bioactive glass. Chatzistavrou et al. has been reported the growth of a hydroxyapatite layer on the surface of a bioactive glass coated dental ceramic substrate [3]. Kontonasaki et al. has been reported that the bioactive dental glass ceramic composite promotes a higher cell proliferation than that of the unmodified porcelain [19]. Chatzistavrou et al. has been studied the sol–gel derived bioactive glass ceramic composite material for dental application [14]. They found that the prepared bioactive glass ceramic composite shows the similar characteristics to that of a commercial dental ceramic [14]. They also observed the cell attachment and proliferation of the periodontal ligament and gingival fibroblasts cells on the surface of the developed material [14].

Furthermore, the addition of fine alumina to bioactive glass ceramic composite may increase the mechanical properties. Alumina has the biocompatibility, high hardness and good mechanical properties [22–24]. The glass is toughened and strengthened when a crystalline material such as alumina is added to it. This is because the crack cannot pass through the fine alumina particles as easily as it can pass through the glass matrix [25]. This technique has found the application in dentistry in the development of aluminous porcelain particles in a glassy porcelain matrix for porcelain jacket crowns [25]. Most dental ceramics that have a glassy matrix utilize reinforcement of the glass by a dispersed crystalline substance [24,25].

Furthermore, mechanochemically derived leucite based bioactive glass ceramic composite have been previously synthesized by us. A superior bioactivity and the moderate mechanical properties have been investigated [1]. Subsequently, the aim of present study is to enhance the mechanical properties without affecting the biological and thermal properties of the leucite based dental ceramic composite. The results have also been compared with a commercial product (VITA VMK 95) to validate the feasibility of the prepared composite. The composite material does not cause any significant apoptosis of SCC-25 cells and allow the cells to grow over its surface indicating a high degree of biocompatibility. Further, no work has been reported on the effect of addition of alumina to the mechanochemically synthesized leucite based bioactive glass ceramic composite.

2. Materials and methods

2.1. Preparation of leucite, bioglass and LTF

AR grade potassium carbonate, aluminum oxide and silicon dioxide (Loba Chemie Pvt. Ltd., Mumbai, India) was weighed and mixed in a stoichiometric ratio of leucite. This mixture was ground for 6 h in a Fritsch Pulverisette high-energy ball mill and subsequently fired at 1100 °C as discussed in our previous work [7]. Bioglass® 45S5 was prepared on a lab scale by melting in a platinum crucible at 1400 °C. The molten glass was quenched in water and dried at 110 °C for 3 h subsequently milled to pass a 350 BSS mesh. A similar procedure was used for the preparation of LTF [8].

Table 1
Chemical compositions of the composites.

Sample coding	Leucite	Bioglass	LTF	Alumina
Al-0	40	40	20	0
Al-2	39	39	20	2
Al-4	38	38	20	4
Al-8	36	36	20	8

*LTF: Low temperature frit.

2.2. Formulation of composites

Composites (referred as Al-0, Al-1 and Al-2) were prepared by mixing the different wt. % of mechanochemically derived leucite, bioglass, LTF and fine alumina. Compositions are given in Table 1. The mixture was ground in an agate mortar for 20 minutes to get a homogenous mixing. The milled mixture was pelletized using a uniaxial hydraulic press by applying a load of 200 MPa. The pressed pellets were heat treated at 950 °C using a VITA VACUMAT 40 T furnace. The heating schedule is given in Table 2.

2.3. Characterizations

2.3.1. Phase analysis, microstructure and CTE

X-ray diffraction (XRD) of the composite powders (before and after firing) was carried out to confirm the phase formation using a portable X-ray diffractometer (Rigaku, Japan) with Cu K_α radiation employing Ni filter and operating at 30 mA and 40 kV. Diffraction peaks were analyzed using standard JCPDS file (PDF-2 database 2003). All the sintered specimens were polished using emery papers of grade 400–800 (Sia, Switzerland) followed by polishing on a velvet cloth using diamond paste of grade 1/4-OS-475 (HIFIN). These polished specimens were chemically etched with 2% hydrofluoric acid for 10 s. Finally, they were dried and gold sputtered to make a smooth conducting surface. Micrographs of the coated samples were recorded using scanning electron microscopy (SEM) (INSPECT 50 FEI).

The rectangular bars of dimension $50 \times 10 \times 10\ mm^3$ were made in a similar manner as discussed earlier for CTE measurements. CTE and glass transition temperature (T_g) of the composites were studied using a dilatometer (VB Ceramic Consultants, India).

2.3.2. Flexural strength, apparent porosity and bulk density

Flexural strength measurements were done according to ASTM C78 M using a universal testing machine; Instron 3344 (Germany). The specimens were fractured in three-point crossways fit with the 20 mm span between the two supports (three point bending). The load and the corresponding deflections were recorded. The standard deviation, S of the flexural