DENTAL MATERIALS 33 (2017) 477–485

Available online at www.sciencedirect.com

ScienceDirect

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

Stereolithography: A new method for processing dental ceramics by additive computer-aided manufacturing

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ARTICLE INFO

Article history:
Received 7 July 2016
Received in revised form
23 January 2017
Accepted 30 January 2017

Keywords:
Dental crown
Stereolithography
Ceramics
CAD/CAM
Additive technology

ABSTRACT

Objectives. The aim of this study was to compare the physical and mechanical properties of stereolithography (SLA)- manufactured alumina ceramics of different composition to those of subtractive- manufactured ceramics and to produce suitable dental crown frameworks.
Methods. The physical and mechanical properties of a control and six experimental SLA ceramics prepared from slurries with small (S) and large (L) particles (0.46 ± 0.03 and $1.56 \pm 0.04\,\mu$m, respectively) and three dry matter contents (70%, 75%, 80%) were evaluated by dynamic rheometry, hydrostatic weighing, three3-point flexural strength measurements, and Weibull analyses, and by the micrometrics measurement of shrinkage ratio before and after the heat treatments.
Results. S75 was the only small particle slurry with a significantly higher viscosity than L70. The viscosity of the S80 slurry made it impossible to take rheological measurements. The viscosities of the S75 and S80 slurries caused deformations in the printed layers during SLA manufacturing and were excluded from further consideration. SLA samples with low dry matter content had significantly lower and densityflexural strengths. Only SLA samples with a large particle size and high dry matter content (L75 and L80) were similar in density and flexural strength to the subtractive- manufactured samples. The 95% confidence intervals of the Weibull modulus of the L80 ceramic were higher (no overlap fraction) than those of the L75 ceramic and were similar to the control (overlap fraction). The Weibull characteristics of L80 ceramic were higher than those of L75 ceramic and the control. SLA can be used to process suitable crown frameworks but shows results in anisotropic shrinkage.
Significance. The hH High particle size and dry matter content of the L80 slurry allowed made it possible to produce a reliable ceramic by SLA manufacturing with an anisotropic shrinkage, and a density, and flexural strength similar to those of a subtractive-manufactured ceramic. SLA allowed made it possible to build up a dense 3D alumina crown framework

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http://dx.doi.org/10.1016/j.dental.2017.01.018

with controlled shape. Further studies on the marginal adaptation and shrinkage model of alumina crown frameworks will be required to optimize the process.

1. Introduction

Subtractive computer-aided design (CAD) and computer-aided manufacturing (CAM) technologies have led to major improvements in dentistry [1]. They make it possible to produce reliable restorations with accurate dimensions [2] and to reduce manufacturing time [1]. However, these processes are limited by the waste of raw material (loss of unused portions of blocks and difficulty in recycling excess material) and heavy wear of milling tools. Microscopic cracks, which can weaken restorations, can also appear in objects due to the milling process [3].

Additive manufacturing processes avoid these limitations by building objects layer-by-layer. While such processes are already being used to manufacture metal and polymer prototypes [1], the shaping of ceramics for dental applications is still in its infancy [4,5]. Ceramics can be additively manufactured by polymerizing an inorganic binder in a ceramic powder bed (3D printing) [6], selective laser sintering (SLS) [7], ceramic slurry printing (direct inkjet printing) [8], or stereolithography (SLA) [9]. SLA produces scaffolds in calcium phosphate hydroxyapatite with the higher accuracy, surface quality, and mechanical properties [9] than the other processes by selectively curing a photosensitive ceramic slurry using an ultraviolet beam. Curing with ultraviolet light makes it possible to work under artificial light without causing polymerization during the slurry preparation process.

Alumina and zirconia ceramics, the gold standard for crown frameworks in polycristalline ceramic, possess good mechanical resistance [10] and are thus the focus of SLA additive manufacturing research and development [9]. Even though additive-manufactured zirconia has the highest flexural strength [11], its high refractive index [12] limits curing depth compared to alumina. This parameter is of utmost importance for SLA manufacturing [9], making alumina a good material for optimizing additive processes for preliminary dental research.

Since the viscosity of a slurry influences the reliability of complex structures, this parameter must be adapted to the SLA-manufacturing process. The incorporation of ceramic particles in curable resins modifies their rheological behavior. Increases in viscosity depend on the nature, dry matter content, and particle size of the ceramic [13,14]. The dry matter content of slurries has to exceed 50% (v/v) to avoid deformation and crack formation during thermal treatments. However, the higher the dry matter content the higher the viscosity [9]. As such, a compromise between a high dry matter content and low viscosity that is compatible with SLA manufacturing must be found.

The photosensitive cured polymer used to assemble ceramic particles during SLA manufacturing is burnt out during debinding. This increases the porosity and reduces the mechanical strength of sintered objects [5], preventing their use as crown frameworks, which require the highest density possible.

In addition, crown frameworks require high flexural strength to ensure the durability of restored teeth that are subjected to masticatory strains [15]. The 3-point flexural strength of these materials should be at least 300 MPa (ISO 6872:2008) if they are to be employed for clinical uses. Ceramics used for dental restorations must also be very reliable. Structural reliability is generally based on two Weibull distribution parameters: the Weibull modulus and the Weibull characteristic strength [15,16]. The Weibull modulus allows lower range strength values whose distribution is typical of ceramic materials (do not follow Gaussian distribution) to be used [17]. A high Weibull modulus indicates a high degree of homogeneity and smaller variations in flexural strength. Both parameters have a major impact on the clinical success of ceramic restorations [15].

Most reports in the literature dealing with ceramic SLA manufacturing focus on the impact of slurry composition on polymerization [9,13] and the optimization of photoinitiator, diluent, and polymerizable monomer concentrations in ceramic slurries. However, no data is available with regard to the impact of variations in particle size and dry matter content on the flexural strength and Weibull characteristics of SLA-manufactured dense ceramics. While SLA-manufactured temporary crowns are commercially available [1], there are no reports in the literature on the feasibility of using SLA-manufactured crown frameworks composed of dense ceramic.

The aim of the present study was thus to compare the physical and mechanical properties of SLA-manufactured alumina ceramics of different composition (dry matter content, particle size) and viscosity to those of subtractive-manufactured ceramics, and to demonstrate the feasibility of producing suitable dental crown frameworks by the SLA process.

The four null hypotheses tested were: (1) variations in the composition of the ceramic slurry used in the SLA-manufacturing process do not influence viscosity; (2) there is no difference in density between SLA-manufactured and subtractive-manufactured alumina ceramics; (3) there is no difference in flexural strength between SLA-manufactured and subtractive-manufactured alumina ceramics with high Weibull characteristics; (4) there is no difference in shrinkage between SLA-manufactured and subtractive-manufactured alumina ceramics; and (5) it is possible to produce dental crown frameworks by SLA manufacturing.

2. Materials and methods

2.1. Specimen preparation

2.1.1. Experimental groups

Slurries were prepared using small (S) (CT3000SG; Almatis, PA, USA) and large (L) (CT1200SG; Almatis, PA, USA) particle size