



Characterization of ceramic components fabricated using binder jetting additive manufacturing technology



J.A. Gonzalez^{a,b,*}, J. Mireles^{a,c}, Y. Lin^c, R.B. Wicker^{a,c}

^a W.M. Keck Center for 3D Innovation, The University of Texas at El Paso, El Paso, TX 79968, USA

^b Department of Metallurgical and Materials Engineering, The University of Texas at El Paso, El Paso, TX 79968, USA

^c Department of Mechanical Engineering, The University of Texas at El Paso, TX 79968, USA

ARTICLE INFO

Article history:

Received 16 December 2015

Received in revised form

1 March 2016

Accepted 10 March 2016

Available online 10 March 2016

Keywords:

Binder jetting technology

Alumina

Additive manufacturing

ABSTRACT

Binder jetting additive manufacturing is an emerging technology with capability of processing a wide range of commercial materials, including metals and ceramics (316 SS, 420 SS, Inconel 625, Iron, Silica). In this project, aluminum oxide (Al_2O_3) powder was used for part fabrication. Various build parameters (e.g. layer thickness, saturation, particle size) were modified and different sintering profiles were investigated to achieve nearly full-density parts ($\sim 96\%$). The material's microstructure and physical properties were characterized. Full XRD, compression testing, and dielectric testing were conducted on all parts. Sintered alumina parts were achieved with an average compressive strength of 131.86 MPa (16 h sintering profile) and a dielectric constant of 9.47–5.65 for a frequency range of 20 Hz to 1 MHz. The complexity offered by additive processing aluminum oxide can be extended to the manufacturing of high value energy and environmental components for environmental systems (e.g. filters and membranes) or biomedical implants with integrated reticulated structures for improved osseointegration.

© 2016 Elsevier Ltd and Techna Group S.r.l. All rights reserved.

1. Introduction

Fabrication of ceramics in the macro scale is difficult due to their brittle and hard nature, especially when producing complex geometries of fired ceramics. Ceramics, in general, have a wide range of applications ranging from biomedical implants to engine components in the aerospace and automotive industry (Doore and Hubner, 1984). In this research, alumina was selected for fabrication because of its wide applicability in industries such as electronic, biomedical, and aerospace. Alumina is a high-temperature ceramic that provides stable electrical properties and mechanical robustness [41], it is also a structural ceramic due to its wear resistant properties and its ability to withstand severe mechanical stresses in corrosive and thermal environments [28]. In addition, alumina is cataloged as a versatile ceramic due to the wide variety of applications as a dielectric material, optical (when transparent and used in transparent envelopes in street lamps), biomedical (hip implants) and thermal (packages for integrated circuits). Some of its main properties are stability at high temperatures, permeability, high surface area and thermal shock resistance [8]. Alumina can be present as α , γ and β phases, being α -alumina

present in ambient atmospheres, which has an hexagonal closed packed structure, with a melting point of 2054 °C and a hardness equal to 9 on the Mohs scale [30]. Advantages of this ceramic in traditional manufacturing are its low cost and ease of fabrication by slip casting, pressing, and injection molding [29]. Machining of alumina ceramics can be expensive due to the level of experience required and material waste that can be generated during the process [24]. It is important to note that alumina has a wide range of purity that depends on the amount of elements such as Silicon within the alloy. High purity alumina ($> 95\%$) is typically used for high voltage electrical substrates and insulation while low purity alumina (~ 60 to 85%) is primarily used for temperature resistance. In this research low purity alumina precursor powder was used to demonstrate the fabrication of alumina using binder jetting additive manufacturing technology [2,7,10].

Additive manufacturing (AM), or the method of creating a three-dimensional object through a layer-by-layer process, has been widely researched for its potential to process ceramics. One method that has been extensively investigated is Fused Deposition of Ceramics (FDC), developed by Rutgers University [4]. This process is based on a material extrusion method used to fabricate polymers. In order to process conventional ceramics, such as SiO_2 , Si_3N_4 , Al_2O_3 , lead zirconium titanate (PZT), the development of organic binders, binder removal techniques, and sintering conditions have been developed [1]. In a study conducted by Allahverdi et al., alumina structures with photonic bandgap structures were

* Corresponding author at: Department of Metallurgical and Materials Engineering, The University of Texas at El Paso, El Paso, TX 79968, USA.

E-mail address: jagonzalez24@miners.utep.edu (J.A. Gonzalez).

fabricated with the use of wax as support material [4]. Laser Engineered Net Shaping (LENS) has been used to fabricate α - Al_2O_3 in different shapes such as cylinders, cubes and gears. Compressive testing results showed anisotropic properties that could not be altered by heat treatment [6]. By having a mixture of resin and ceramic where a slurry containing alumina powder and a UV curable monomer, among other things, provided the necessary means to fabricate three dimensional parts by stereolithography [20,21]. In addition, by adding alumina particles to create colloidal ink, direct ink-jet printing of ceramics was achieved by Lewis in 2002 to provide tailored properties [25]. In this research, binder-jetting technology was used as a means for fabrication. Binder jetting technology is a powder bed based technology that selectively deposits a binder layer-by-layer onto a powder bed to create a three-dimensional object. Upon fabrication, a green body is obtained which undergoes a heat treatment cycle that burns out the binder and sinters the powder particles. The goal of this research was to study the feasibility of fabricating ceramic structures that can be used as packages for sensors or electronics exposed to high temperature environments [35,39,42,5].

2. Materials and methods

2.1. Fabrication

Fabrication was achieved by the binder jetting process using the ExOne M-Lab system (Irwin, PA serial number: 0600H2). The process consists of fabricating three-dimensional parts (previously designed by computer-aided design (CAD) and uploaded in the system as a '.stl' file) from powder precursor material. Powders are bonded together in a layer-by-layer fashion. The ExOne M-Lab printer consists of a two-bed system (as shown in Fig. 1); one bed is for the base powder material and the other for part fabrication. Powder layers are spread with a roller while the bed is mechanically moving in the X-direction. Once the powder layer is uniformly spread, the powder bed returns to its original position where binder droplets are selectively deposited through a piezoelectric printhead for part fabrication. Once the binder is deposited, the powder bed moves below the heater, where heat is provided for a set amount of time to achieve powder binding. This is considered as the fabrication of one layer (one full cycle), and the process continues until part fabrication is complete.

For this project, a 1.75:1 ratio of powder and binder deposition was used, which means that the equivalence of one layer and three fourths of a layer of powder from the powder bed (feed) are used to fabricate one layer in the build bed to achieve better powder packing. Based on successful results described elsewhere [18]

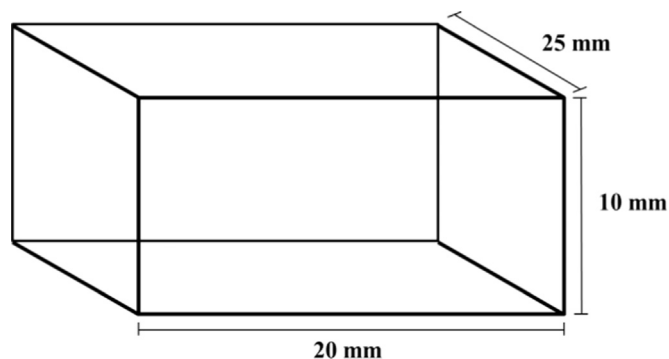


Fig. 2. Original CAD file used in order to measure the shrinkage that occurs after sintering.

fabrication of Al_2O_3 parts was performed using binder saturation of 60% and various layer thicknesses. The layer thickness was determined based on the particle size of the powder that was being used. Three different powders were used for fabrication and three layer thickness parameters were used for each powder. The first layer thickness that was used corresponded to the particle size. Then half the particle size and double the particle size were used as the layer thickness to determine its influence on final sample property. After the select layer thicknesses were used for all the powders, the powders were combined and mixed evenly to achieve a large distribution of particle size, in order to determine if the density could be improved. For the mixed powders, the range of layer thickness depended on using the largest, median, and the smallest used on the previous runs. Based on the amount of empty space that is present due to the packing of the powder during each layer, the binder will replace such space in order to remove any empty space. After fabrication is finished, the building envelope is placed in the oven at 195 °C for 2 h. This step is performed to cure the binder selectively placed in the fabricated part, allowing the separation of the fabricated geometry from the unbound powder. After the binder is cured, the parts are brushed to remove unbound powder and prepared for sintering.

2.2. Powder

Aluminum oxide grinding powder purchased from Ted Pella, Inc. was used for the fabrication process. Three different grits were used in order to determine the effect of particle size on build quality (e.g. density). The three different grits used were 240, 320, and 400. Note that the grit size is related to particle size where 240 grit is 53 μm , 320 grit is 45 μm , and 400 grit to 30 μm .

2.3. Sintering profile

Two different schemes of sintering time and temperature were used in order to determine how the shrinkage and density would change. The furnace used for sintering was a Rapid Temp Model 1710 FL Laboratory Box Furnace by CM Furnace Inc. The highest temperature that was reached for both sintering profiles was kept consistent at 1600 °C. The heating rate that was used was 10 °C per minute, and parts were sintered in atmospheric pressure with no other gas being introduced during the process. The part was sintered at two different dwell durations: 2 h and 16 h.

2.4. Characterization

Characterization of shrinkage was defined by the change in part dimensions caused by the sintering. That is, by sintering voided space will be filled by surrounding particles that diffusion and bond with one another, which will reduced the overall geometry

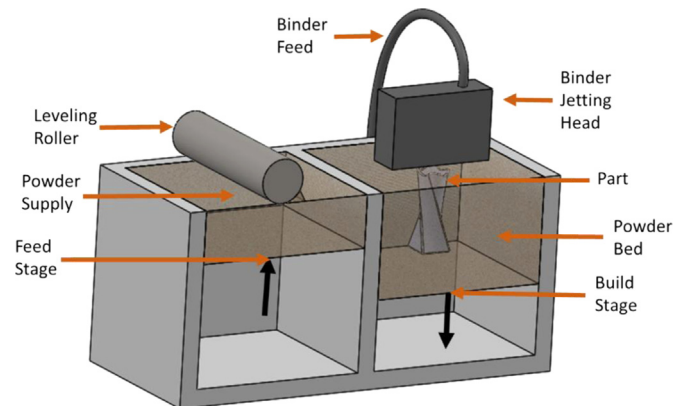


Fig. 1. Schematic representing the ExOne components used for the fabrication process.

Download English Version:

<https://daneshyari.com/en/article/1458591>

Download Persian Version:

<https://daneshyari.com/article/1458591>

[Daneshyari.com](https://daneshyari.com)