BOLETÍN DE LA SOCIEDAD ESPAÑOLA DE CERÁMICA Y VIDRIO xxx (2017) xxx–xxx

ELSEVIER

BOLETIN DE LA SOCIEDAD ESPAÑOLA DE
Cerámica y Vidrio
www.elsevier.es/bsecv

Fabrication and characterisation of ceramics via low-cost DLP 3D printing

Giftymol Varghese[a], Mónica Moral[a], Miguel Castro-García[a], Juan José López-López[b], Juan Ramón Marín-Rueda[a,b], Vicente Yagüe-Alcaraz[b], Lorena Hernández-Afonso[c], Juan Carlos Ruiz-Morales[c], Jesus Canales-Vázquez[a,*]

[a] Instituto de Energías Renovables, Paseo de la Investigación 1, Universidad de Castilla-La Mancha, 02071 Albacete, Spain
[b] Print3D Solutions, Paseo de la Investigación 1, 02071 Albacete, Spain
[c] Dpto. Química, Facultad de Farmacia, Universidad de La Laguna, 38200 Tenerife, Spain

ARTICLE INFO

Article history:
Received 21 July 2017
Accepted 20 September 2017
Available online xxx

Keywords:
Ceramics
DLP 3D printing
Photopolymerisation
Photogrammetry
Green body

ABSTRACT

A stereolithography-based additive manufacturing technique has been used for the fabrication of advanced ceramics. A customised 3D printer using a Digital Light Processing (DLP) projector as UV source has been built to fabricate green bodies from photosensitive resins loaded with 25–60 wt% of alumina, 3- and 8-YSZ. The 3D-printed bodies were then sintered in the 1200–1500 °C and exhibited thermal stability. As expected, higher ceramic loadings rendered objects with higher density for a given sintering temperature. The limit of solid loading in the resin is approximately 60% and beyond those contents, the extra ceramic appears as powder loosely adhered to the sintered objects. Photogrammetry was used to evaluate the accuracy of the 3D printing process and highlighted a marked deviation between the CAD model and the resulting object, particularly in the top part of the specimens, possibly due to the use of volatile solvents which cause changes in the photoresins used. Nevertheless, that problem may be overcome by thermostatising the printer vat and/or using solvents with higher boiling point. The results obtained suggest the potential application of low cost DLP 3D printing techniques to process ceramics for a number of applications including ceramic fuel cells, piezoelectrics, dental applications, etc.

Fabricación y caracterización de cerámicas medinate impresión 3D DLP de bajo coste

Palabras clave:
Cerámicos
Impresión 3D DLP
Fotopolimerización
Fotogrametría
Cuerpo verde

RESUMEN

Se ha empleado una técnica de fabricación aditiva basada en la estereolitografía para la producción de cerámicas avanzadas. Se ha diseñado y construido una impresora 3D personalizada empleando como fuente de UV un proyector DLP para fabricar cuerpos verdes a partir de resinas fotosensibles cargadas con el 25-60% en peso de alúmina, 3-YSZ y 8-YSZ. Los cuerpos impresos mostraron estabilidad térmica tras los correspondientes tratamientos de sinterización entre 1.200 y 1.500 °C. Como era de esperar, los mayores contenidos de sólido

* Corresponding author.
E-mail address: jesus.canales@uclm.es (J. Canales-Vázquez).

https://doi.org/10.1016/j.bsecv.2017.09.004

Please cite this article in press as: G. Varghese, et al., Fabrication and characterisation of ceramics via low-cost DLP 3D printing, Bol. Soc. Esp. Cerám. Vidr. (2017), https://doi.org/10.1016/j.bsecv.2017.09.004

en las resinas dieron lugar a objetos con mayores densidades relativas para cada temperatura de sinterización. El límite de carga sólida en las resinas es aproximadamente un 60%, y por encima de estas cantidades, el contenido extra de cerámico aparece como partículas de polvo débilmente adheridas a los objetos sinterizados. Se empleó la fotogrametría para evaluar la precisión del proceso de impresión 3D donde se puso de manifiesto una marcada diferencia entre el modelo CAD y el objeto impreso, especialmente en la parte superior de los especímenes, posiblemente debido al uso de disolventes volátiles que provocan cambios en las fotorresinas empleadas. Sin embargo, este problema puede paliarse termostatizando el contenedor de la resina de la impresora y/o mediante el empleo de disolventes con mayor punto de ebullición. Los resultados obtenidos sugieren la potencial aplicación de técnicas de impresión 3D DLP de bajo coste para el procesado de cerámicos para aplicaciones como pilas de combustible cerámicas, piezoeléctricos, aplicaciones dentales, etc.

Introduction

Ceramics because of their aesthetic value, biocompatibility and physico-chemical properties are highly suitable for biomedical, biochemical and diagnostic applications [1]. Some of the most researched and commonly used bioceramics include pure alumina (Al_2O_3) [2,4,8], pure zirconia (ZrO_2) [3,5,6], alumino-silicates, zirconia doped with yttria, vitreous carbon and calcium phosphate based ceramics [1]. For the past few decades, the chemical composition of the bioceramic was the most relevant parameter, though in recent times the focus has been driven to the relation between processing and the resulting mechanical and thermal properties in order to improve both performance and durability. As a consequence, ceramics such as alumina and zirconia have proved more adequate properties than most metals in implants due to their resistance to corrosion and the ability to withstand very high temperatures [5–7].

In the last 3 decades, additive manufacturing (AM) has emerged as a technology that can be used to fabricate objects with complex geometries straight from a computer-aided design (CAD) file [9,10]. This group of techniques may be applied to a wide range of materials, from polymers to metals and also ceramics [1]. Although it was first conceived for rapid prototyping, 3D printing has undergone outstanding progress and becomes gradually more popular, particularly due to some advantages compared to other manufacturing techniques as is the possibility of fabricating complex geometries, rational use of materials, relatively low time consumption and they can be user friendly. AM includes a number of technologies such as Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), Stereolithography Apparatus (SLA), Inkjet-Based Systems and others [9]. In the case of ceramics, FDM may not provide enough resolution for applications where a good finish is required such as odonthology or electroceramics as the nozzle tends to be rather large. Inkjet technologies have already been used in ceramics with very good results, although it may be time-consuming when printing out objects others than thin films or high aspect ratio structures. SLS has been reported as an adequate technique for high quality ceramics, although the systems are rather expensive. In the case of SLA, there are rather economic systems to produce ceramics with high output resolution and surface quality [9–12], and moreover the systems could be customised by replacing the laser and using DLP projectors which can also produce high quality ceramics at low cost [13].

Regarding SLA 3D printing of ceramics, Al_2O_3-based resins were characterised by Brady et al. to rapid prototype ceramics with the assistance of a SLA machine [11] and later some ceramic systems were studied [17]. Since then, there has been some progress in this field as reviewed by Ferrage et al. [14]. In that work, the effect of processing upon the control of porosity and prevent the appearance of cracks was pointed out. In any case, most of those works refer to high profile 3D printers and they appear to be restricted to just a few materials. As yttria-stabilised zirconia has its relevance in a range of commercial and industrial sectors and can be efficiently manufactured and characterised, that offered us the motivation to present this novel work on low cost SLA-based manufacturing of alumina, 3 and 8 mol% YSZ. As 3D printed ceramic objects are obtained after the modelling of the geometrical bodies in a CAD software, it is highly relevant to correlate the dimensions of the printed object compared to the original model. In the present study, we have attempted to apply classic photogrammetry and Structure-form-Motion (SfM) algorithm to estimate accurately the changes in the dimensions of the ceramics during the 3D printing process by 3D reconstruction. This classic photogrammetric process is carried out by image acquisition, image measurement using a series of target points with known 3D positions and processing which involves aligning the target points for object reconstruction [15]. On the other hand, in SfM, the geometry of the object, camera positions and orientation are solved automatically without the need to specify a network of targets [16].

Materials and methods

Material preparation and processing

Ceramic-loaded photosensitive resins were prepared using 25–60% (w/w) of alumina (Sigma–Aldrich), 3 and 8% YSZ (Kingda Ceramics), poly(ethylene glycol) diacrylate (Sigma–Aldrich), a UV photo initiator (PI) phenyl bis (2,4,6-trimethyl(benzoyl)phosphine) in 5 ml of an organic solvent