Development and optimization of a Low Temperature Co-fired Ceramic suspension for Mask-Image-Projection-based Stereolithography

Joana Gonçalves Fernandes

MOTIVATION AND OBJECTIVES

CHAPTER II

From the point of view of innovation, Additive Manufacturing (AM) offers an entirely new palette of geometries to play with in the manufacturing of new objects. Thanks to AM, the current concept of product development has been reshaped, opening the door to a new level of customization.

A very much valued characteristic of AM in this fast-paced world is that it allows companies to quickly respond to industry and customer feedback, taking advantage of the latest technologies.

Nowadays, ceramic materials have claimed their due role in AM, mainly for high temperature and biomedical applications. However, it is well known that ceramic materials generally possess low toughness, low ductility, and high crack damage sensitivity, which, combined with the high hardness and high melting temperatures, make them difficult to handle during manufacturing. Furthermore, ceramic materials are also applied to electronic applications where multi-material systems are often needed in order to develop functional components, which add further challenges to the manufacturing process.

SmarTech's forecasted timeline expects an inflection point after 2025 for the adoption of AM of ceramic materials, as a consequence of its technological maturity and its sufficient presence in the market to support serial part production. In fact, the growth perspectives of ceramic AM are exponential and promising, evidenced by the number of companies which are commercializing AM printers for ceramic materials. It is known that the vat-photopolymerization process is the one now adopted for aerospace and medical applications. Furthermore, the expansion to new and high-potential manufacturing areas such as dental, energy, and electronic is expected, followed by its validation and/or adoption in the near future (2025-2028).

This work has been carried out between the University of Barcelona, in the departments of Electronic and Biomedical Engineering and Materials Science and Physical Chemistry, and Francisco Albero S.A.U. (FAE), a company in the automotive field focused on electronic components.

In this regard, the presented work has the main goal of developing ceramic materials for Mask-Image-Projection-based Stereolithography (MIP-SLA) technology, focused on electronic applications. To accomplish this aim, a low temperature co-fired ceramic (LTCC) material was selected, mainly used for radio frequency applications. Moreover, the proof of concept of additive manufacturing technology hybridization and multi-materials printing is also demonstrated, opening the door to new researchers in the field of 3D-2D printing electronic devices, from both the material and technology perspectives.

The MIP-SLA printer machine and its hybridization with the inkjet printing systems was developed by Fundació Privada Centre CIM (F-CIM) under the project *Nuevos procesos de* *impresión híbrida 3D/2D para dispositivos avanzados* (NHIBRID – New Processes of 3D/2D Hybrid Printing for Advanced Devices). FAE and Fundació Bosch i Gimpera- Universitat de Barcelona (FGB-UB) also participated in the development of this project, focused on the material formulation and characterization.

The main goal of this work is the achievement of ceramic pieces manufactured by MIP-SLA technology.

Thus, to achieve the main goal of this work, the challenge is the development of a LTCC photocurable suspension for MIP-SLA with the appropriate rheological and photocurable behavior, allowing for its printability in the developed MIP-SLA machine.

The photocurable LTCC suspension consists of ceramic particles dispersed in a suitable photocurable resin, which must polymerize in the visible light range. Apart from this, the maximization of the solid load is desired to avoid the formation of defects during the thermal treatment and to increase the final density of the ceramic pieces.

In this regard, a stable photocurable suspension with a high load of LTCC ceramic particles with the proper rheological behavior is desired for the MIP-SLA process. Another objective is the stability of the suspensions which takes an important role in the sedimentation rate of the LTCC suspension, which must be low as possible. On the other hand, the photopolymerization behavior must be appropriate for the printing process, to avoid the delamination of the part during the thermal treatment.

It is known that the higher the number of ceramic particles, the higher the viscosity and the lower the cured depth due to the light scattering by the particles. At the same time, the sedimentation rate increases at low values of viscosity for a certain percentage of ceramic particles. Thus, one of the main goals of this thesis is the development of a stable suspension that reaches the compromise between these four requirements: low viscosity, high solid load, high photosensitivity, and low sedimentation rate, i.e., high stability.

The objective is to determine the limits of the printing process, analyzing the resolution, fidelity of pattern transfer, and accuracy of the printing process using the optimized LTCC suspension. Thus, the involved phenomena during the photopolymerization such as light scattering, non-uniformities of the light projection along the building platform and shrinkage during the polymerization, are key factors in understanding the printing process.

The analysis and understanding of thermal treatment parameters and their repercussion on the final results is the key to successfully achieving the main goal of this work, which is to obtain final ceramic pieces.

The printed object contains the polymeric part which must be removed (debinding) and then sintered for the densification of the final ceramic piece. This is the most difficult and time-consuming step of the whole process. The so-called debinding is one of the most challenging steps of the SLA-based technology of ceramic materials. In this sense, a detailed study of the debinding process is needed for the understanding of the degradation of the resin during the thermal debinding. For this to happen, the optimization of the temperature rate and used atmosphere during the thermal treatment is also an objective of this work.