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# STUDY OF THE PROPERTIES OF CERAMIC PARTS PRINTED BY STEREOLITHOGRAPHY ON AN OPEN SOURCE MACHINE

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## 1. Introduction

High-performance ceramic materials have been widely used in the aerospace, biomedical, automotive and electronics industries due to their exceptional properties, such as high strength and hardness, resistance to high temperatures and corrosion.

Traditional manufacturing methods, such as molding or machining, still face difficulties in manufacturing complex ceramic geometric shapes.

Additive manufacturing technologies offer an opportunity to alter and complement traditional manufacturing paradigms. The ability to directly 3D print parts from digital designs drastically changes design and prototyping workflows. Key technologies contributing to the growth of the 3D printing market include the light curing segment, which accounted for 21% of the 3D systems market in 2021.

Vat photopolymerization (VPP) allows dense parts and fine details to be printed thanks to the high resolution provided by the thin layers it can print. Therefore, VPP 3D printers are an excellent choice for jewellery applications, dentistry, and other types of high-precision functions.

That said, this ceramic additive manufacturing technology requires a high investment that not all companies can afford; the cost of a technical ceramic VPP 3D printer ranges from $150,000 to over $500,000.

3D printing with ceramic resin is also a relatively complex operation involving long preparation times and delicate post-processing steps, such as washing off excess resin, curing, and sintering.

## 2. Objective

This initial research, which is part of a wider investigation in the framework of the **3DKeralux** project, intends to study the influence of ceramic particle size and the use of dispersants in the printability and characteristics of the printed parts.

The aim is to develop ceramic resins that can be printed on an open source VPP machine.

## 3. Methodology and materials

In this first part of the project, a photopolymer resin (Genesis Development Resin Base, Thethon 3D) was used as the base material. Three types of alumina were selected to study the influence of the particle size (Figure 1). Three types of dispersant were employed in this study: Ammonium polymethacrylate solution (D), Acrylate monomer (S) and Oleic Acid (OA).

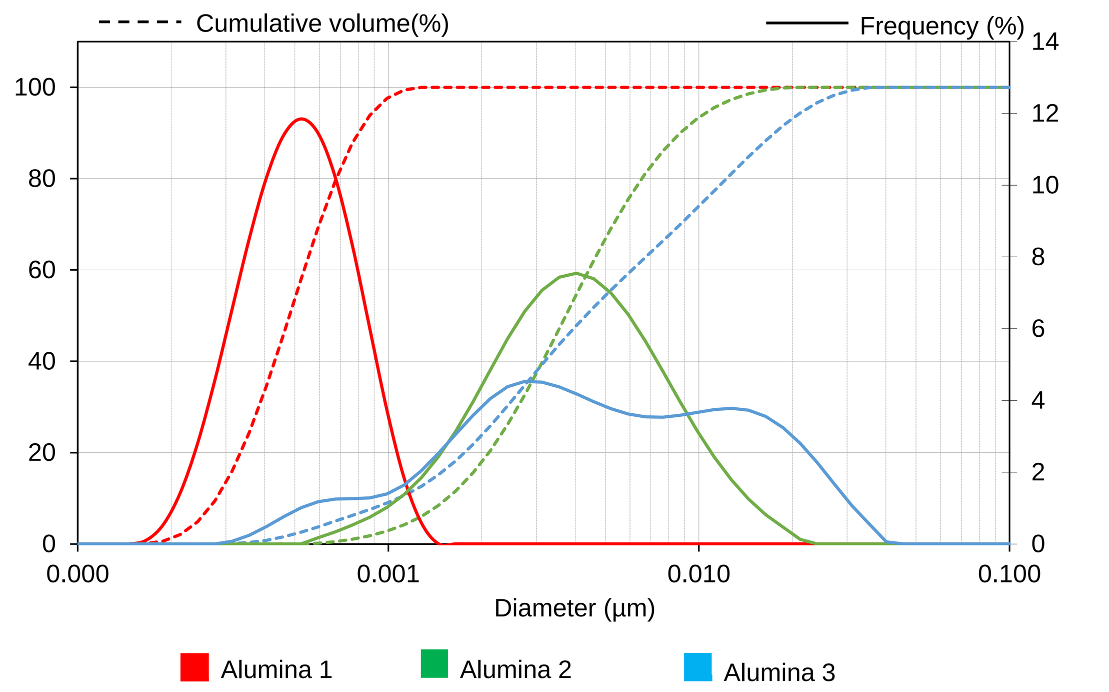


*Figure 1. Particle size distribution (cumulative volume and frequency) of samples: Alumina 1, alumina 2, alumina 3.*

The photopolymer resin was mixed with the dispersant at 25ºC for 5 minutes and then the alumina powders were gradually added and mixed for another 30 minutes with a turbo agitator. Table 1 shows the compositions of the slurries elaborated with different dispersants type, dispersant concentration, alumina type and alumina loading.

*Table 1. Composition of the $Al_2O_3$ resin slurries elaborated with different dispersant type, dispersant concentration and solid loading.*

| Reference | Alumina | Solid loading (vol%) | Dispersant | Dispersant concentration (wt%) |
|---|---|---|---|---|
| Al140D1 | 1 | 40 | D | 1 |
| Al140D10 | 1 | 40 | D | 10 |
| Al140D3 | 1 | 40 | D | 3 |
| Al140D6 | 1 | 40 | D | 6 |
| Al140N | 1 | 40 | none | 0 |
| Al140OA1 | 1 | 40 | OA | 1 |
| Al140OA10 | 1 | 40 | OA | 10 |
| Al140OA6 | 1 | 40 | OA | 6 |
| Al140S1 | 1 | 40 | S | 1 |
| Al140S10 | 1 | 40 | S | 10 |
| Al140S6 | 1 | 40 | S | 6 |
| Al150S1 | 1 | 50 | S | 1 |
| Al210D3 | 2 | 10 | D | 3 |
| Al220D3 | 2 | 20 | D | 3 |
| Al230D3 | 2 | 30 | D | 3 |
| Al240D3 | 2 | 40 | D | 3 |
| Al250S1 | 2 | 50 | S | 1 |
| Al340D3 | 3 | 40 | D | 3 |
| Al350S1 | 3 | 50 | S | 1 |

To determine the effect of dispersant concentration on slurry sedimentation, a visual test was carried out. The slurries were kept in darkness at room temperature for 19 days.

The measurement of the rheological parameters was carried out on a Bohlin CVO-120 rheometer, where the applied shear force is controlled, and the deformation produced per second is measured. During the test, the sample is kept thermostatically controlled at a temperature of 25 °C.

The flow tests consisted of a linearly increasing ramp of shear force and a linearly decreasing ramp of shear force.

The curves obtained as a result of the test, called flow curve and viscosity curve, represent the shear stress or strain and viscosity as a function of the shear rate.

The colloidal stability of the suspensions was performed using a stability and suspension analyser (Turbiscan Lab Expert, Formulaction) based on multiple light scattering principle. The equipment has an electroluminescent diode which emits in the near infrared. When the beam hits the sample, part of the light is transmitted and part is backscattered, depending on the turbidity of the sample.

Parts were printed on a MSLA printer (SL1, Prusa) at different exposure time.

The mechanical strength was determined by bending 70x20x3 mm parts on three support points. The tests were conducted on a mechanical testing machine (5889, Instron) at a constant bending rate of 5 mm/min.

To test the printability of the slurries and dimensional accuracy, geometrically complex parts were printed (Figure 7).

## 3. Results

Figure 2 shows the sedimentation behaviour of the dispersants at different concentrations (1%, 6% and 10%). The OA additive starts to sediment almost immediately. Furthermore, with a volume of 10% of all dispersants, the slurry sediments faster.

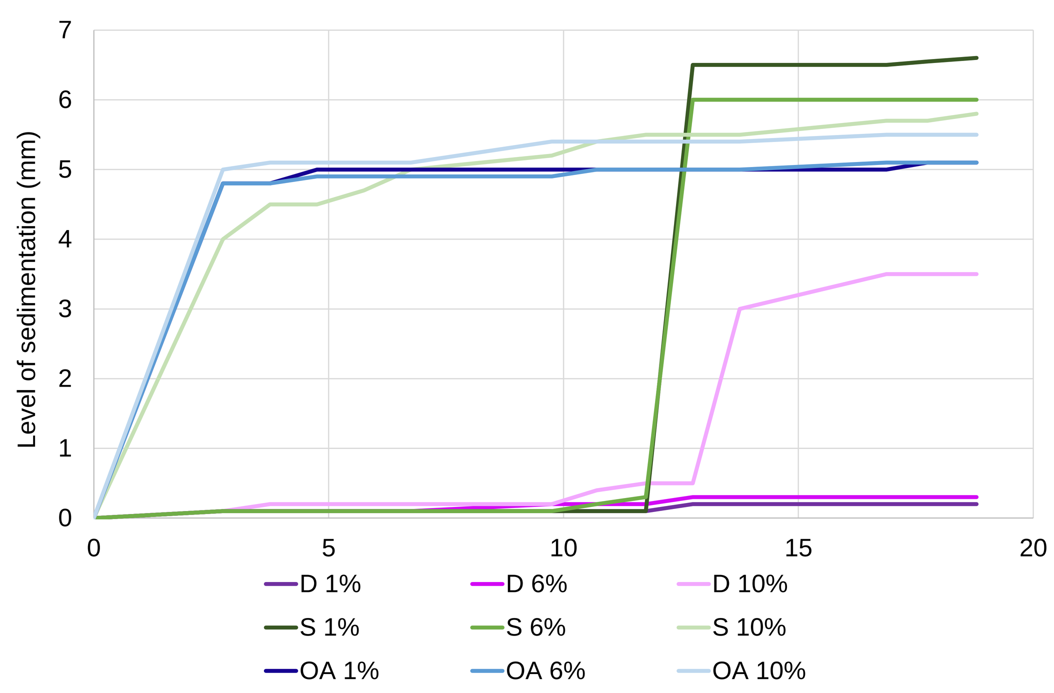


*Figure 2. Study of sedimentation with different concentrations and type of dispersant over time.*

The colloidal study data are shown on Figure 3. OA dispersant was excluded since, as shown in figure 2, it shows a rapid sedimentation. The dispersant concentration used was 1%. A mix of alumina and photopolymer resin without dispersant was also tested for comparison.
The reference sample Al140S has the lowest sedimentation compared to the rest of the samples tested, which is confirmed by the lower amount of backscattered light at the bottom of the measuring vials. It also shows the lowest particle agglomeration.

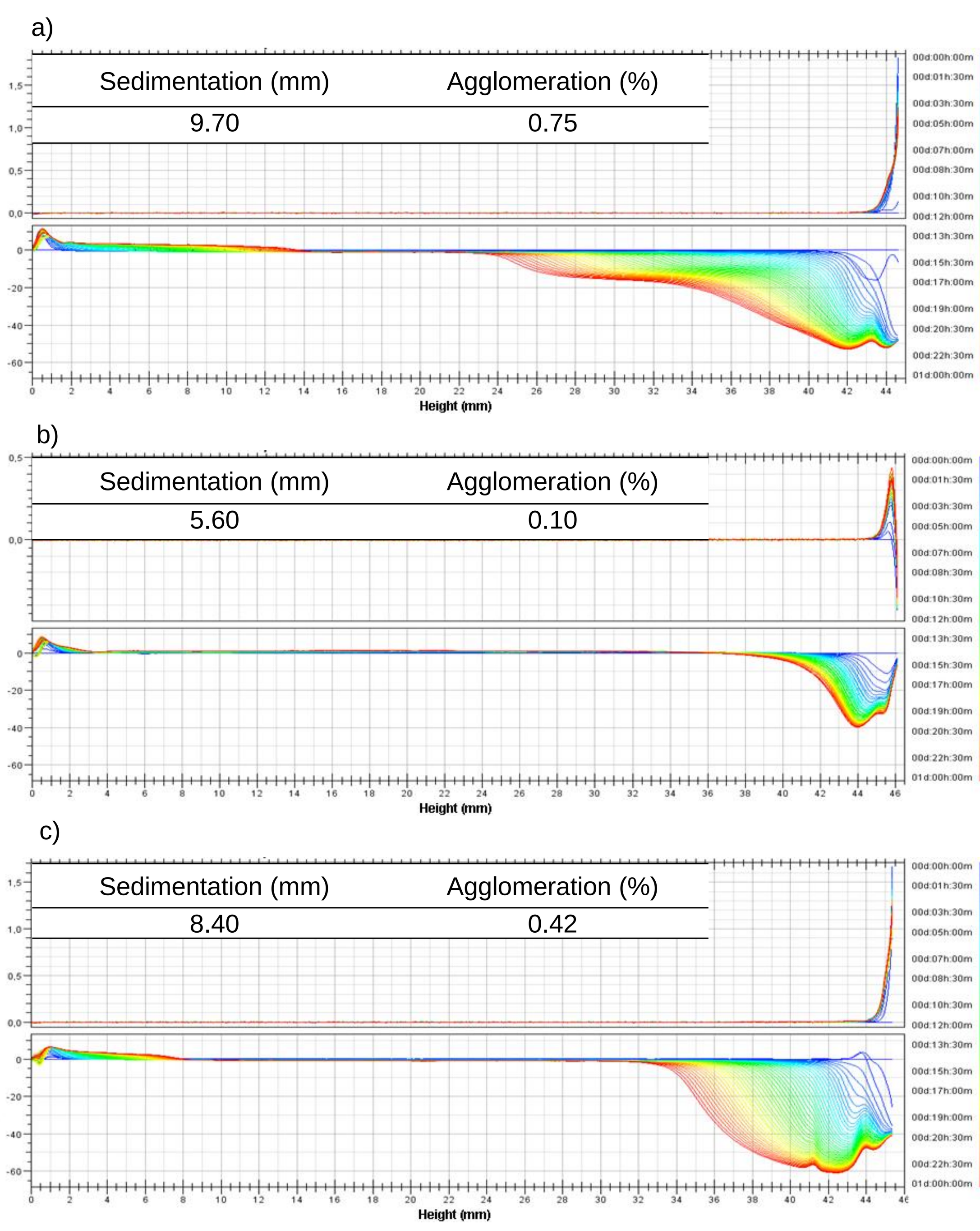


*Figure 3. Colloidal stability of the samples for 1 day at 30ºC: a) Al140N, b) Al140S1, c) Al140D1.*

Figure 4a shows the increase in flexural mechanical strength as the solid loading increases. In Figure 4b a correlation between the particle size and the mechanical strength can be seen, showing how larger particles result in higher mechanical strength.

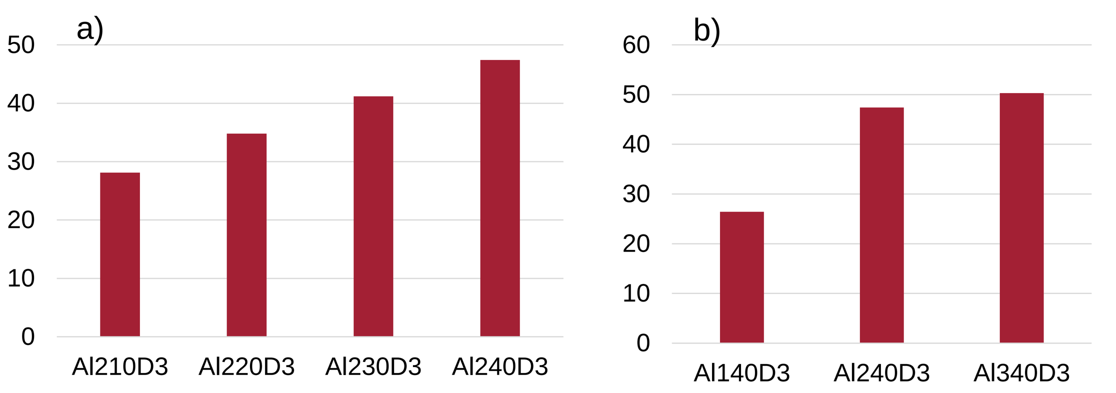


*Figure 4. Mechanical flexural strength of the green parts (MPa).*

Another characteristic studied was the influence of alumina solid content in the mixture (Figure 5a) and the particle size on the printability of the samples (Figure 5b). The results show that the higher the solid loading, the longer the exposure time must be to achieve a correct print; especially the initial exposure time. They also show an increase in printing time as the particle size grows.

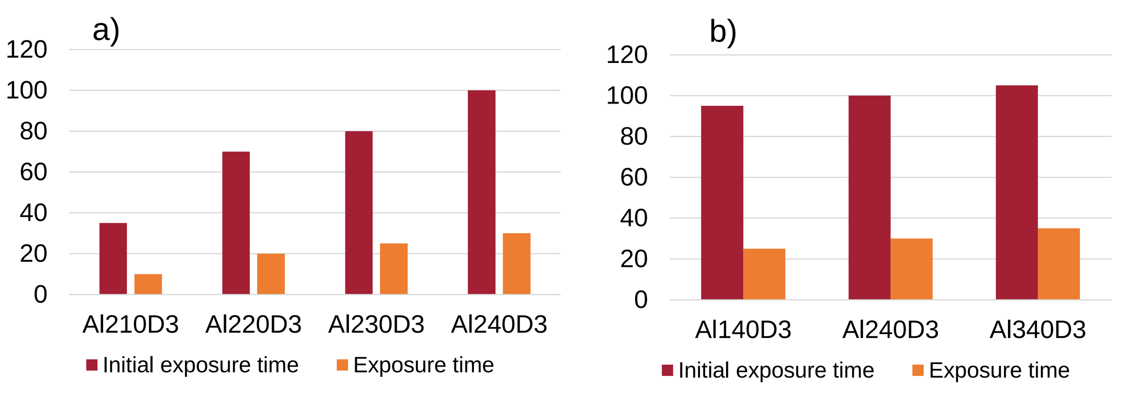


*Figure 5. Printing exposure time (s).*

Figure 6 shows the rheological behaviour of suspensions, it can be said that all three compositions present a Newtonian fluid behaviour, where the viscosity is constant regardless of the shear rate. All formulations have viscosity values lower than the reference value of 3000 mPa suggested in the literature. (C. Hinczewski et al., Ceramic suspensions suitable for stereolithography, 1998), being therefore ideal to be used by the presented technique.

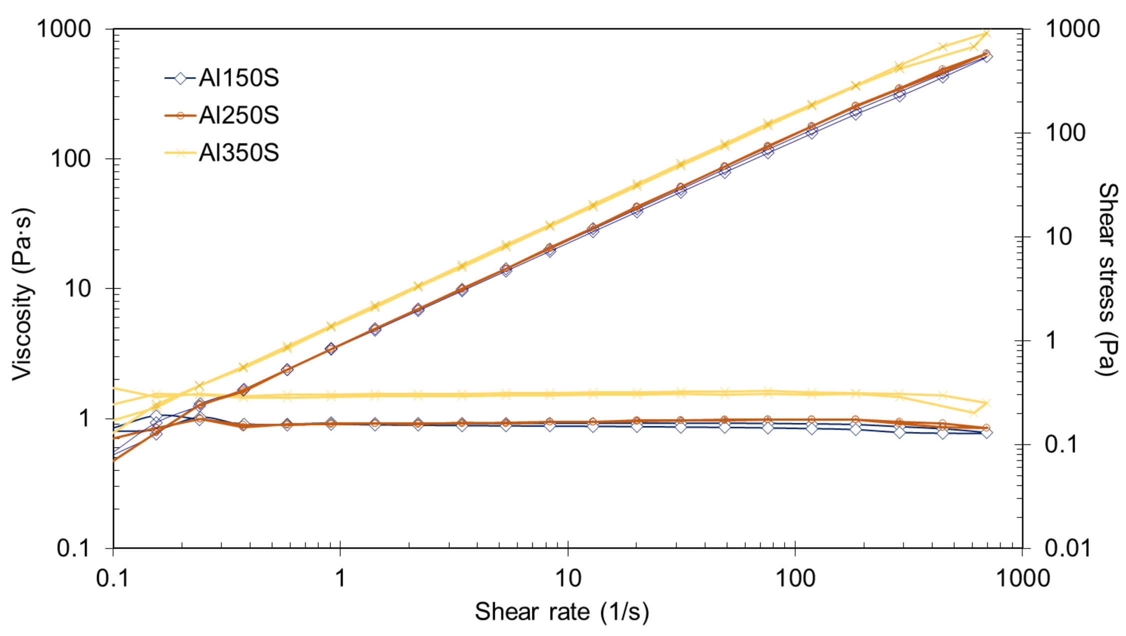


*Figure 6. Viscosity results obtained for the different suspensions.*

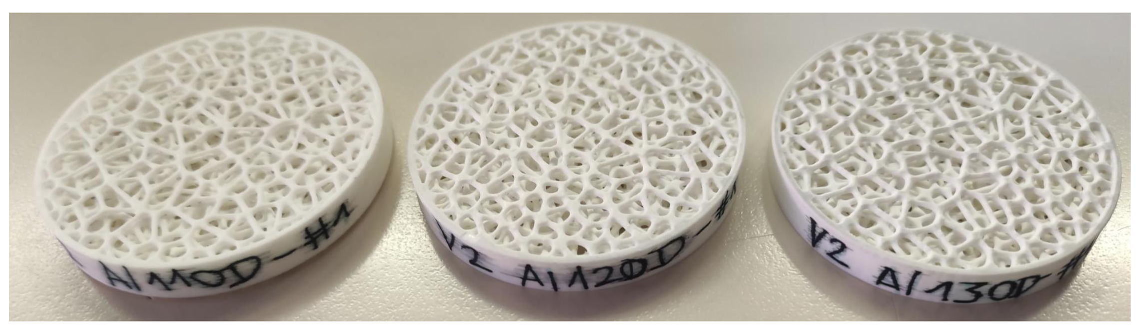

*Figure 7. Green printed parts.*

## 4. Conclusions

After analysing all the results obtained, several conclusions can be drawn:

- Dispersant OA has a rapid sedimentation that renders it useless for the purpose of this project.
- The best result for all dispersants was obtained with a concentration of 1%.
- From the colloidal analysis, it can be determined that the dispersant S gives the best results both in terms of sedimentation and agglomeration, significantly improving the values compared to the slurry without dispersant.
- Mechanical bending tests show, as expected, that the higher the solid load, the higher the strength obtained. An increase in strength is also observed the larger the particle size.
- The improvement in mechanical strength achieved by both the growth in particle size and the increase in alumina content results in a longer exposure time.
- The slurries obtained so far show a viscosity close to 1000cps, which has proved to be suitable for printing. A slight increase in viscosity is observed with larger alumina particle size.
- The viscosity obtained by the compositions is fit for the technique as is proven by the the correct printing of more complex parts.

The next steps of the project will be to increase the solid concentration of alumina, fire the parts and analyse their density, mechanical strength and shrinkage.

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