The 5 Secrets of Ceramic Additive Manufacturing

White Paper

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Executive Summary

Most people are probably not aware that Additive Manufacturing (AM) was invented more than 30 years ago. Even with that length of time, AM remains a technology that is just now gaining acceptance worldwide in the aerospace, automotive, and medical industries. One area where AM is still in relative infancy is making ceramic components.

One of the primary challenges with Stereolithography-based ceramic AM is the fact that the material is actually a slurry that consists of ceramic powder suspended in a photo-reactive resin. This slurry adds complexity to the AM process because the viscosity and suspension of particles are additional variables that have to be managed.

The PERFECT-3D division of Renaissance Services has identified five areas that most people are surprised to discover as they probe into the details of ceramic AM. This white paper was created to provide the interested reader with an overview of those insights associated with the 3D printing of ceramic parts.

Introduction & Overview

The news media would have one believe that it is easy to 3D print just about anything you can imagine – buy a 3D printer and some material, and presto, you have a finished part. For practical industrial applications, additive manufacturing still has many challenges and limitations (for the sake of simplicity, this paper uses 'additive manufacturing' and '3D printing' interchangeably). The Renaissance Services PERFECT-3D division has a half-decade of experience with ceramic additive manufacturing (AM) in support of the aerospace & defense industry. Over that period, PERFECT-3D has identified five areas that most people are surprised to discover as they probe into the details of ceramic AM. This document was created to provide the interested reader with a brief summary of those interesting secrets associated with the 3D printing of ceramic parts.

Secrets of Ceramic 3D Printing

1) Ceramic pottery is very different than engineered ceramics

When you say the word 'ceramic', many people think of coffee cups and dinner plates where specific dimensions and mechanical properties are hardly considered. Naturally, this is not the focus of making parts for airplanes and automobiles. The PERFECT-3D focus is commonly referred to as *technical ceramics* or *engineered ceramics* – i.e., industrial applications involving high precision and demanding requirements. There are a wide variety of applications for engineered ceramic parts:

- Electronic Components
- High Temperature Bearings
- Casting Process Aids

Figure 1 shows an example of a high-precision casting mold made from ceramic AM.

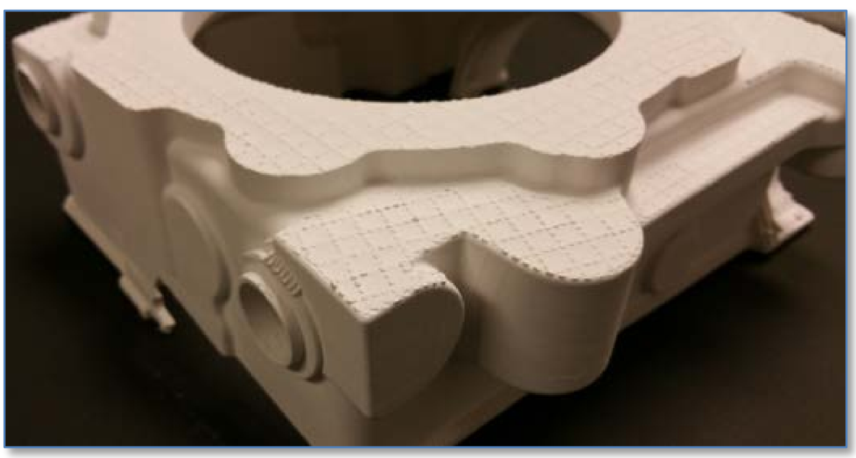

Figure 1 – Example of Engineered 3D-Printed Ceramic Mold

2) The control of the ceramic material is very critical to successful AM

When people consider 3D printing, they often think about the common thermoplastics such as those used in fused deposition molding (FDM). These low-cost FDM printers operate similar to glue-guns where the material is melted and laid down one on-top-of-the-other to build-up a part in 3D.

At this point in AM technology maturation, the 3D printing process that is considered the most viable for ceramics is based on vat photopolymerization, also known as stereolithography (SLA). As shown in figure 2, the vat houses a liquid material that is reactive to the light patterns projected from a light source. Successive layers are solidified as the part is lowered into the vat.

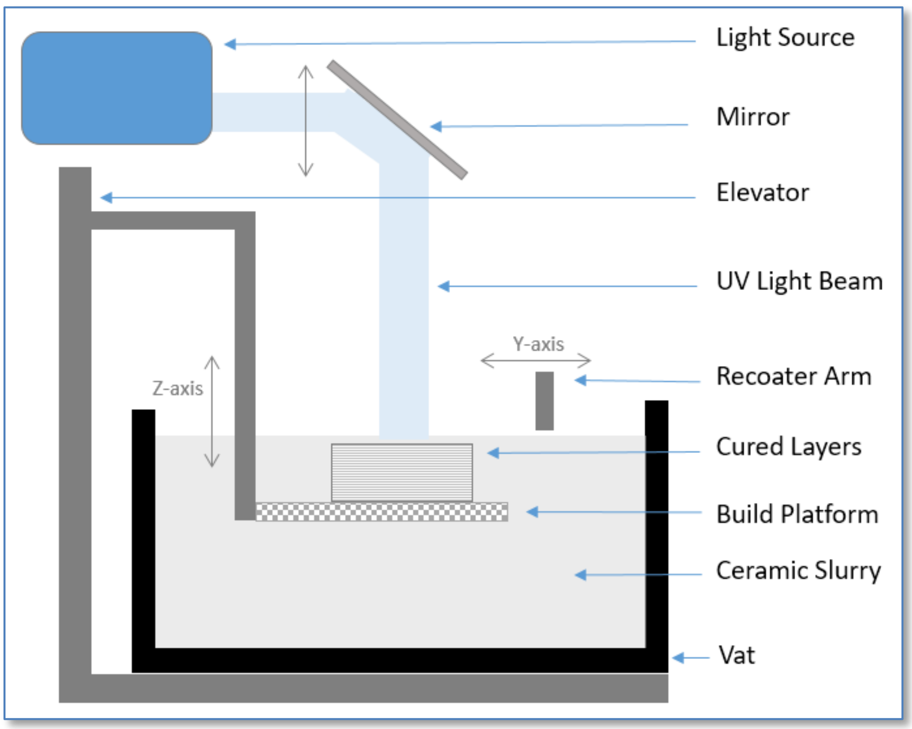

Figure 2 – Cross-Section Diagram of Vat Photopolymerization

The ceramic material for 3D printing is actually a slurry consisting of the solid ceramic powders suspended in the liquid resin (see Figure 3). The resin is primarily a monomer that solidifies into a polymer when impacted by photons of lights. This polymer behaves as a temporary binder holding the ceramic particles together in the desired shape of the part.

Ceramic powders or flours typically consist of some combination of silica, zircon, and alumina with each of these having critically different particle sizes and shapes. Most companies involved in metal or ceramic AM have started to realize that control of particle size and distribution is critical, and in many ways, unprecedented. Variations in the ceramics and resin can lead to great frustration and yield issues in the printing builds.

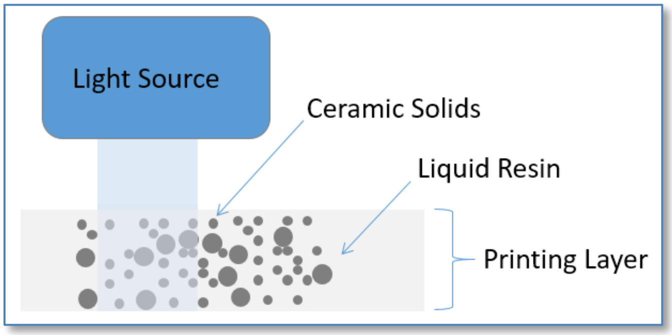

Figure 3 – Powder and Resin Components in Slurry

3) Making ceramic AM parts requires critical pre- and post-processing

A ceramic part coming off the 3D printer is typically referred to as a 'green' part. This means that the part has a resin that had solidified as a binder, but the ceramic particles are not strongly bonded. Since the binder is just intended to temporarily hold the ceramic particles together to form the part, ceramic AM requires a thermal cycling of the part after printing. Figure 4 highlights some of the additional special processes that are required in ceramic AM versus the more traditional AM processes.

The 'firing' step includes a burnout of the temporary binder, but more importantly it involves the sintering of the ceramic particles. This high temperature sintering (typically higher than 2000F) actually densifies and bonds the ceramic particles together. This firing cycle requires very controlled heating of the ceramic parts over an extended period of time. Variations in the firing cycle can greatly impact the structural integrity as well as the mechanical properties of the ceramic part.

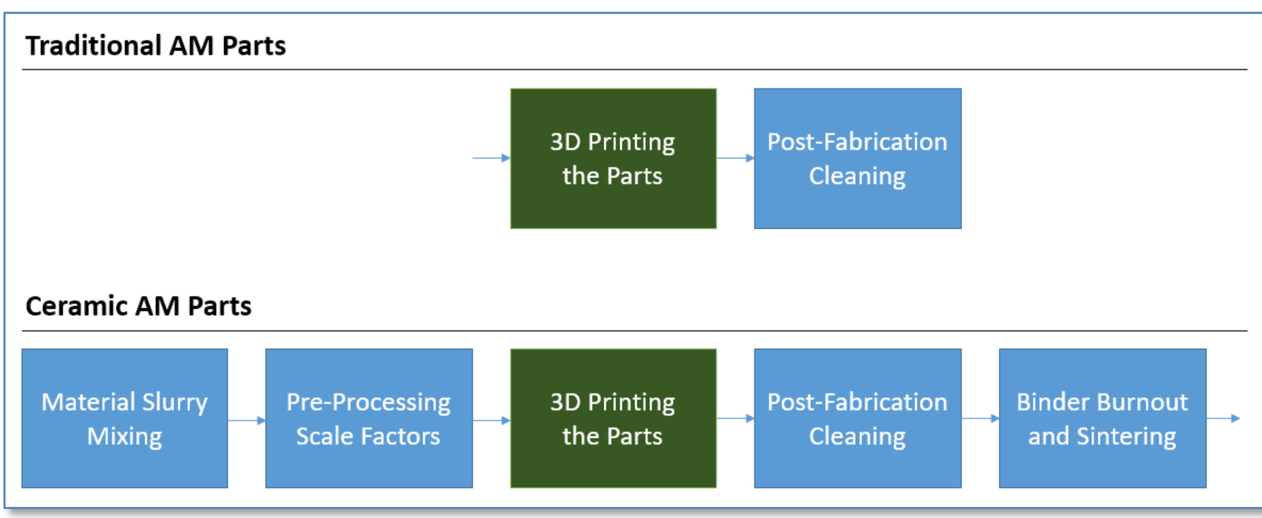

Figure 4 – Additional Factors Affecting Ceramic AM

4) The ceramic AM process must accommodate inherent shrinkages

Depending upon the ceramic material recipe used (type of ceramic, amount of solids loading, etc.), the amount of part shrinkage can vary substantially. Many process factors can also affect the shrinkage such as orientation of the parts during the 3D printing as well as the specific printing parameters. As importantly, shrinkage not only transpires during printing, but it also occurs to a greater extent during the firing cycle.

To make ceramic parts that meet demanding dimensional requirements, all of these factors have to be taken into consideration when using AM.

5) A powerful application for ceramic AM is tooling for making castings

Changing the manufacturing process for making a part for aerospace, automotive, or medical applications (e.g., 3D printing a metal housing instead of casting the part), typically requires a total re-qualification of the part. This involves various costly destructive tests as well as detailed and labor-intensive engineering analyses.

As a result, PERFECT-3D focuses on 3D printing of ceramic process aids for investment castings. As shown in Figure 5, this includes:

- Cores – the ceramic component that is used to make hollow spaces in a casting
- Molds – the ceramic shell that forms the shape of the overall casting
- Filters – the ceramic device for removing impurities during the metal pour

Figure 5 – PERFECT-3D Ceramic Cores, Molds, and Filters

By focusing the 3D printing effort on the ceramic tooling, the finished metal part can still be made using the original foundry process. This leverages AM to make a part at less cost and shorter time-frame while simultaneously avoiding the costly and time-consuming re-qualification efforts.

Summary & Conclusion

Ceramic additive manufacturing is starting to show promising results. Compared to conventional processes, the 3D-printing of ceramics has the potential to reduce tooling costs and leadtime by more than 70%.

To learn more about these secrets and how ceramic AM can work for you, contact:

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