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MECHANICAL CHALLENGES OF 3D PRINTING CERAMICS USING DIGITAL LIGHT PROCESSING

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Abstract

Digital light processing (DLP) 3D printing can be used for manufacturing complex structures using a variety of materials, which would be nearly impossible using traditional manufacturing methods. Recent work at Sandia National Laboratories uses DLP technology for additive manufacturing of complex alumina structures, using photocurable resins loaded with micron or submicron alumina particles. These resins are printed using a DLP 3D printer to produce a "green part." The work presented here will discuss the mechanical challenges associated with printing alumina using commercially available DLP and stereolithography 3D printers, including the design of a custom DLP 3D printer to address identified mechanical challenges, thereby leading to improved print versatility and quality.

Introduction

Additive manufacturing technologies offer a compelling opportunity to disrupt and complement traditional manufacturing paradigms. The ability to directly print 3D parts from digital designs dramatically alters prototyping and design workflows, and provides an efficient fabrication route for low-volume production of complex or custom parts [1]. Among the suite of additive manufacturing techniques, digital light processing (DLP) offers an accessible and efficient method for 3D printing and allows straightforward fabrication of complex parts impossible to machine using traditional methods [2, 3]. This technique uses a high-powered projector to print 3D structures layer-by-layer by selectively curing exposed photopolymer resins, using a typical printer assembly similar to that shown in Figure 1.

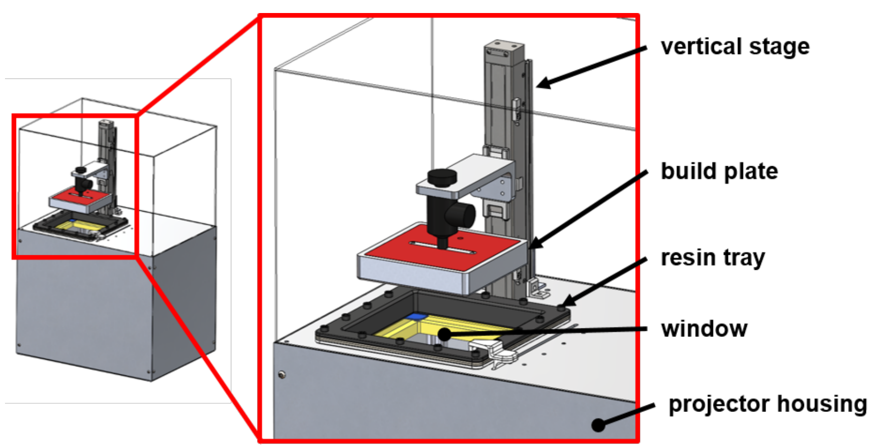

Figure 1: Digital render of the printer assembly and key parts.

Despite its promise, common DLP systems have traditionally focused on polymer manufacturing due to its reliance on photocurable resins, limiting the scope of potential applications [4]. Adapting this technology for ceramic printing using ceramic-loaded photopolymer resins offers many advantages [5]. In recent research at the Advanced Materials Lab at Sandia National Laboratories, DLP and stereolithography (SLA) 3D printing have been used to manufacture complex ceramic parts. In this work, commercial and modified commercial printers are used to experiment with a range of materials, printing methods, and print parameters. Due to the nature of the materials, these experiments are lengthy and have a high rate of failure when compared to other methods of manufacturing ceramics, with the most common failures identified as dropping, sticking, splitting, and flaking. To mitigate these common failures, modifications to existing commercial printers were explored, along with the design of a modular photocurable resin printer to test new materials and print techniques, and offer customizability for future needs.

Common Print Failures

Common print failure mechanisms are classified here as dropping, sticking, splitting, and flaking. These are summarized here, including a brief description, possible causes, and mitigation attempts.

Dropping

Dropping occurs when a part begins printing but drops from the build plate. This most likely occurs due to improper initial layer adhering time, or improper build plate prep. Sanding or scratching the build plate prior to printing usually solved this issue. Other solutions included incorporating a UV-backlit build plate, and using a different metal build plate. The custom printer design incorporates a modular build plate system to accommodate different build plates.

Sticking

Sticking is similar to dropping, but in this case only a layer of cured material sticking to the resin tray will print. This usually indicates the build plate was not lowered enough at the start of the print, or the material is not compatible with the build plate. As described above, certain materials require certain build plates for optimal printing. Sticking is the most common failure type observed during these experiments. The material which failed most often due to sticking was a custom Genesis and alumina material.

Based on experiments with ceramic loaded materials, Porcelite, a silica loaded resin by Tethlon 3D, adheres best to a UV-backlit build plate cured over with Porcelite. Porcelite also seems to adhere to most surfaces including aluminum sanded with 180 grit sandpaper and glass. Genesis base resin by Tethlon 3D loaded with alumina adheres best to a heavily scratched copper build plate, but often fails to produce any part or consistent results.

Splitting

Splitting occurs when printed parts break off the build plate, with a significant amount of material remaining adhered to the build plate. This is most likely due to the process in which the printed parts peel from the resin tray base. The most common type of resin tray uses a silicone base covered with a thin film to promote part separation. These types of resin trays create a pulling force on the printed part during separation, most likely causing delicate ceramic printed parts to split mid-print. The custom printer design incorporates a stretched film resin tray to reduce the pulling force on the printed part, preventing parts from splitting.

Flaking

Flaking occurs when material surrounding the printed part is inadvertently cured. This usually happens in DLP 3D printers as the projected layer image usually has a “glow” which over-cures surrounding material. This usually does not cause a print to completely fail, but flakes of cured material can block subsequent layers, and create final parts with difficult to remove artifacts. In these experiments, lowering the projector intensity usually solves this problem. In the custom printer design, a wiper bar is used to keep flakes out of the critical optical areas, leading to more successful prints.

Custom Printer Design

The design for the custom printer includes a high-power UV projector, stretched film resin tray, glass support plate, UV-backlit build plate, and a modular design. Each of these features was carefully implemented to most effectively address the problems identified above. The following paragraphs describe each addition in more detail.

High-Power UV Projector

By including a high-power UV projector, print times could be reduced dramatically. Using the Kudo 3D Titan 3D printer, layer exposure times were over a minute, requiring a full day for typical parts (500+ layers). To address this, the Kudo 3D printer was modified by installing a high-power UV projector (Digital Light Innovations, 3DLP9000 Light Engine). This reduced print times drastically because each layer required only a few seconds of exposure.

Stretched Film Resin Tray

While printing parts using DLP and SLA methods, exposed layers of material usually adhered to anything they are in contact with. The stretched film resin tray is designed to reduce the pulling force on the printed part and allow for parts to easily peel away from the tray. The current design of SLA and DLP resin printers contain trays made of silicone-like material with a sheet of film designed to prevent the part from sticking. The stretched film design allows for parts with large exposed surface areas to peel away from the tray slowly, and over a larger change in height. The traditional design often fails when printing parts with large surface areas exposed, and the part can’t release from the tray in time before the build plate re-lowers. The design for a stretched film resin tray also incorporates a glass support plate for the tray to rest on, ensuring parts always return to the correct location (Figure 2a).

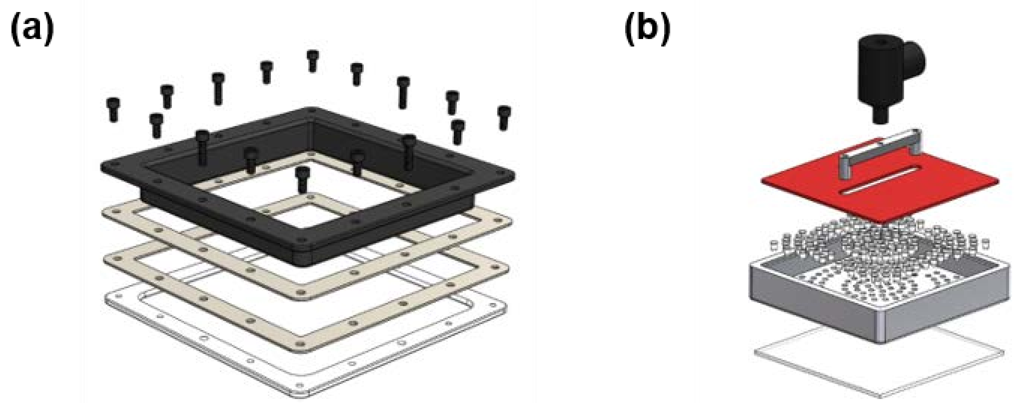

Figure 2: Digital renderings of the custom-designed parts, including (a) the stretched film resin tray and (b) the UV-backlit build plate.

UV-Backlit Build Plate

Traditional SLA and DLP 3D printers use metal build plates. These metal build plates often cause print failures as parts frequently fall off or never adhere. The custom printer uses a UV-backlit build plate to adhere parts for printing (Figure 2b). This build plate uses a glass surface with a UV light source behind to blanket cure a layer of material for the printed part to adhere to. This blanket cured layer encourages the printed parts to stick to the build plate, and not the resin tray material. After the print completes, the part can be removed from the material or broken off the build plate and sanded to the correct dimensions.

Modular Design

Most SLA and DLP 3D printers available offer a replaceable tray design. This allows for easy cleaning and quick material changes. The custom printer uses the same concept of modular resin trays, but also incorporates a modular build plate. The modular build plate allows the printer to print many different types of materials by allowing the user to use specific build plates with certain features, such as a porous ceramic surface or a roughened metal print surface. The printer also uses a modular resin tray design, to allow different resin trays to be added with different features, such as the traditional silicone and stretched film trays which work well for standard resins.

Prototype I

As an initial prototype, a 3D printed resin tray was assembled and filled with an experimental ceramic-loaded resin. The tray uses a stretched Teflon FEP film, designed for use in DLP and SLA 3D printing, and was carefully installed onto the existing printer, the Kudo 3D Titan 2 (Figure 3). A test print with the stretched film design for a resin tray was run, and the stretched film successfully released from the cured material; however, without the glass supporting structure, the build plate could not fully contact the stretched film, causing the print to fail. This prototype confirmed the stretched film resin tray functions correctly, but will most likely require the supporting glass pane. The figures below include images of the prototype resin tray and test setup.

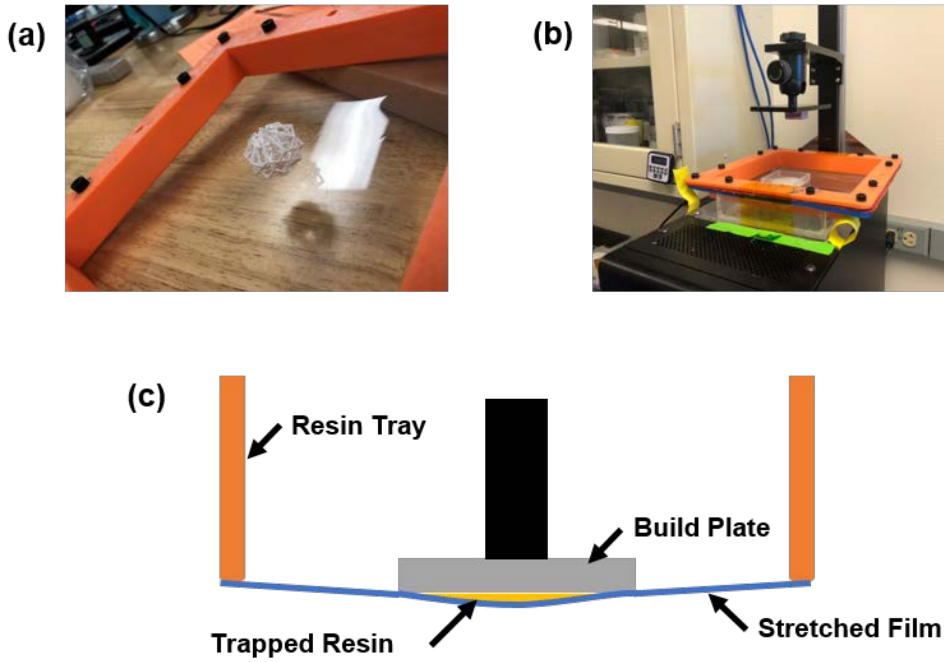

Figure 3: Stretched film resin tray prototyping. (a) Image of the prototype stretched film resin tray with an example ceramic part. (b) Testing of the resin tray installed in the printer. (c) Schematic illustration showing incomplete contact with the stretched film when no supporting glass is used.

Prototype II

The second prototype was of the printer system as a single unit, shown in Figure 4. The code running the printer was the existing code on the Kudo 3D printer. This prototype included the stretched film resin tray and the modular build plates. This prototype was missing the wiper-bar functionality due to a delay in the custom program to run the printer. The following tests and results were produced by this prototype printer.

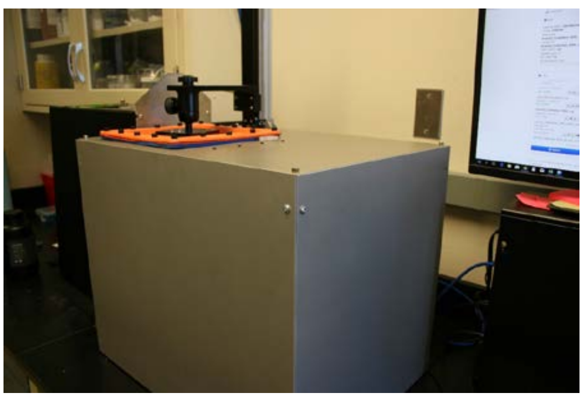

Figure 4: Prototype II

Results

Test 1: Genesis and Copper Build Plate

Test 1 evaluated the printer at the minimum requirement. This test printed in Genesis resin with a scratched copper build plate. This test was designed to evaluate the printer's ability to perform the basic requirement of printing a photosensitive resin. Genesis was chosen, as it has been demonstrated to print using DLP technology and does not contain any additives such as pigments or ceramic particles, and is thus the easiest resin to print.

This test was a success, printing the Kudo 3D Titan 1 test print. This print is designed to evaluate the printer profile, as well as resin resolution. The test print did not successfully complete some of the finer detail features, but this is most likely due to scaling issues of the new printer, which requires detailed calibration. Test 1 was only a proof of basic printer functionality. The images below show the setup and printed part.

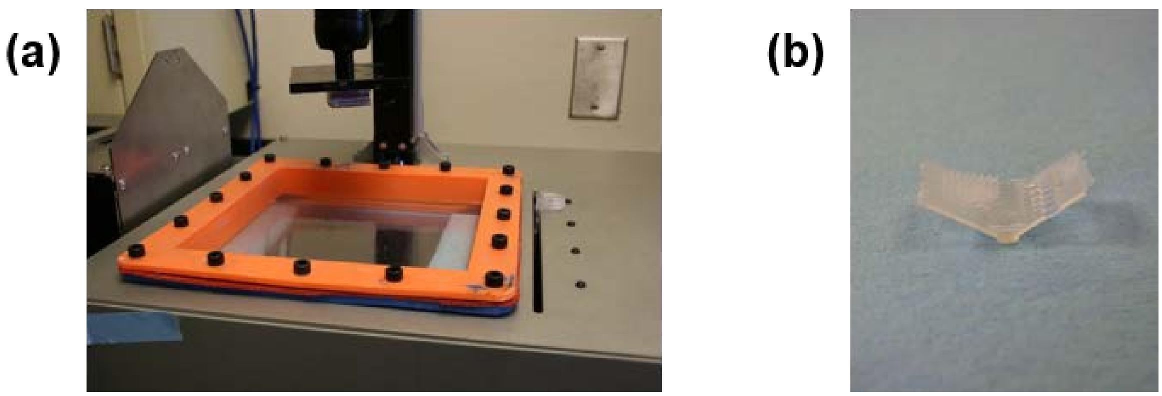

Figure 5: Test 1 setup (a) and result (b).

Test 2: Porcelite and UV-Backlit Build Plate

Test 2 was an attempt to print complex geometry using Porcelite with a UV-backlit build plate. This test was designed to test the printer's ability to print complex structures of a ceramic material. The printer was successful in printing a ceramic cylinder of complex geometry using Porcelite. Below are images of the setup and printed part.

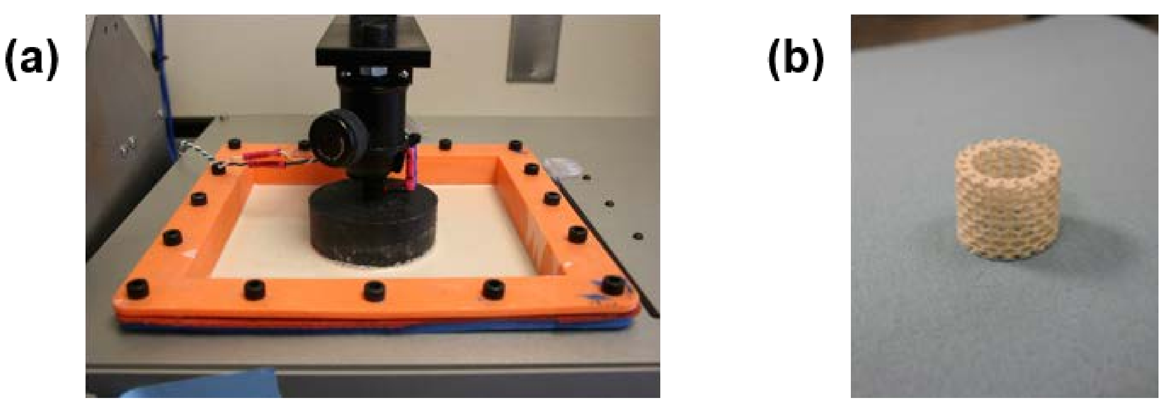

Figure 6: Test 2 setup (a) and result (b).

Test 3: Custom Ceramic Material and UV-Backlit Build Plate

Test 3 was the first test to print a custom ceramic-loaded material, namely alumina-loaded Genesis resin, using the UV-backlit build plate. This test was designed to assess the printer's versatility with a custom ceramic material, a difficult task for all 3D printers tested. The printer failed this test, with the ceramic part not fully adhering to the build plate. This could be due to inconsistency of the cured initial layer, or imprecise leveling of the build plate. This build plate could not be completely leveled due to the glass support plate not being ready at the time of this experiment. Future tests will be performed after the installation of the glass plate.

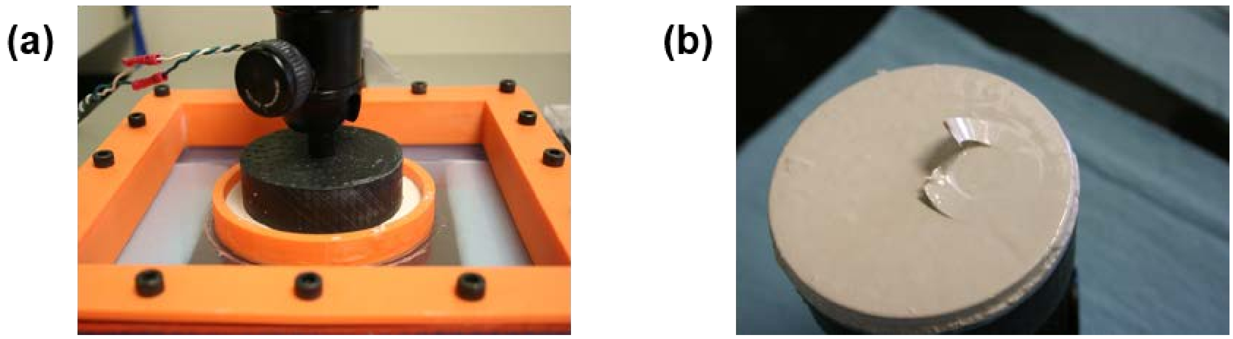

Figure 7: Test 3 setup (a) and result (b).

Test 4: Custom Ceramic Material and Copper Build Plate

Test 4 used the custom ceramic material, but with the scratched copper build plate instead. This test was designed to assess the adherence of the ceramic material to the metal build plate, rather than the UV-backlit build plate. The printer was able to print all but the last ~50 layers of the part. This test revealed that the ceramic material strongly bonds to the stretched film in the resin tray. Removal of the "stuck" features caused the stretched film to tear, indicating the material strongly bonds to the film. Previous tests using commercial 3D printers had similar results with the custom ceramic material.

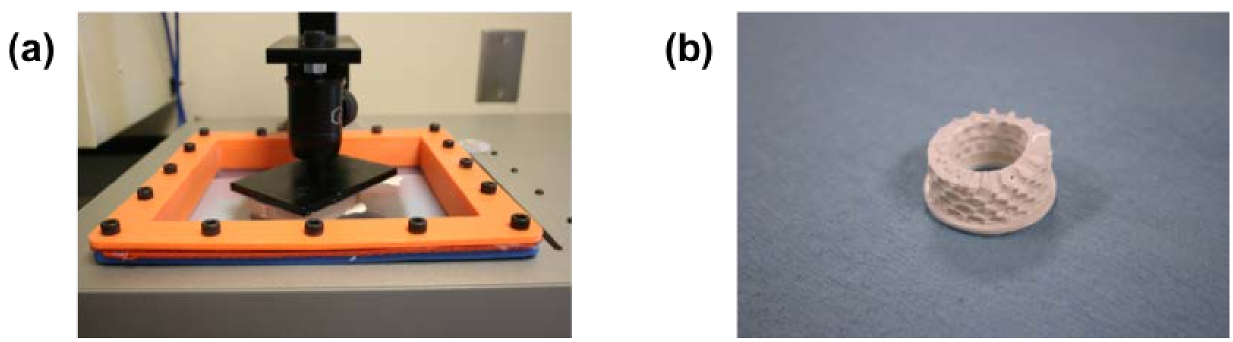

Figure 8: Test 4 setup (a) and result (b).

Conclusion

The above experiments indicate that a stretched film resin tray combined with a UV-backlit build plate can be used to successfully print standard photosensitive resins (such as Genesis) and ceramic-loaded resins (such as Porcelite or our custom resin). Experiments with a custom alumina-loaded resin also show that different formulations of ceramic material have specific printing requirements. These experiments did not show a correlation between the UV-backlit build plate and stretched film resin trays leading to higher print success rates, but these experiments do show the potential in using different printing technologies to successfully print advanced materials. With the modular design and broad versatility of the custom-designed printer, additional opportunities to print advanced materials using DLP/SLA technology are possible.

Future Work

These experiments using DLP/SLA technology demonstrate promise for complex manufacturing of advanced materials. Future work to address remaining challenges includes modifying the printer to include the substituted components, such as the glass support plate, wiper-bar functionality, and machine programming, to allow for more reliable printing. Additional modifications include a larger UV-backlit build plate and a heated build chamber. The larger build plate will allow for larger production of printed parts without creating longer print times (when using DLP technology). The heated build chamber may allow for finer resolution by exploiting changes in resin curing at different temperatures [6]. Finally, successful demonstration of ceramic-loaded resins would support work focusing on alternative high-performance materials such as glass and metals [7], advancing the scope of DLP technology for manufacturing complex geometries for demanding applications.

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