Additive Manufacturing - Ceramic Materials

Abstract

This project explores the function, constraints and implementation of ceramic material in 3D printing. A modern three-dimensional (3D) printing machine mostly extrudes plastics, bioplastics and some metals. However, in recent years, industries like aerospace, medical and automotive have took a close look at the use of ceramics. The origins of ceramic could be traced back to Greek civilizations. Ceramic is a unique material made of clay minerals, which are composed of silica, alumina and water. In order to create magnificent vases, and mugs the clay minerals need to be fired in a kiln at high temperatures. The purpose of this project is to study the use of clay by making a multifunctional 3D printer that is strictly compatible with clay-like materials. I intend to develop a protype printer that allows me to explore the limits and effectiveness with such material.

The prototype will include a lcd screen to navigate through print jobs, custom frame with a guided navigation system using steeper motors at its ends, and an air compressor to extrude the clay. All spatial and calibrations issues will be controlled using an open-source software online. I will generate code using C# and C++ to make printing quick and easy. With this research, I intend to customize a printer that could potentially be used in a larger scale. In such case, the prototype should be designed to maneuver in increments of 5-10 mm (millimeters) to enlarge the printing area. Such printer doesn't exist at the moment so that's what led me to believe a multifunctional and real time adjustment printer will create faster opportunities for designers and scientists.

1. **Topic or thesis statement:**

The goal of this research project is to recognize the primary functions of a ceramic 3D printer, build custom parts and identify the constraints when dealing with such printers. In addition, I would like to find solutions that helps me develop a multifunctional and real time adjustment printer allowing users to move through printing area sizes much easier. Upon completion, I would like to share my knowledge with underrepresented high school students and talk about the use of ceramic 3D printing in the real world.

2. **Purpose:**

Ceramic objects are used in a wide range of applications including, but not limited to, aerospace industry, biomedical and automotive engineering. It's important to note, that most of the function comes from the strength, hardness and temperature stability the material endures. In fact, highly dense ceramic material could withstand up to 1,700 degrees Celsius, that's equivalent to nearly 3,100 degrees Fahrenheit [1]. Also, ceramic materials are known for being extremely brittle so knowing the constraints and limits of designing objects will allow me to make changes to my printer. Structures with complex geometries are nearly impossible to make on today's printers. Designing objects in ceramic is still a very new field explored to date. Usually artists design mugs, vases, plates, etc. by hand. However, designing objects with a wider range of capabilities is exciting and enables people to mesh art and science together.

The emergence of three-dimensional (3D) printing is best known for its revolutionary methods and exceptional practices. In addition, this was a large reason the additive manufacturing industry became one of the largest and sought-after services. According to Marcus [2] and by Sachs et al.[3] 3D printing of ceramic material was introduced in the 1990s. There have been developments in recent times but the functionality remains nearly the same. First the scientist or designer starts with modeling an object using a 3D software. After, the object gets saved into an stl. or obj. file. Once completed the file gets uploaded into a slicing software. The object is sliced into a 2D cross section using discrete points, and layers, hence the name additive. The same philosophy goes for a wide range of printers. Lastly, the file turns into g-code and saved into an SD card ready to print.

3. Previous work

This spring quarter I was part of an independent research project in the art department (ART 199). Here, I studied the mechanics and tool used in a 3D plastic printer under mentoring of my faculty mentor (Department of Arts, UC Irvine). I assembled a Prusa i3 MK3S+ to understand the components in a standard 3D printer. It provided me with a hand on approach and allowed me to recognize issues that occur within the 3D printer. Once I was able to comprehend and execute the solutions, I realized the same processes could be applied to a 3D ceramic printer.

4. Objective: Three-Dimensional (3D) Printer Delta Assembly

To successfully work on my project, I chose to work on a delta style 3D printer. A delta printer is a fast, efficient and provides high print quality. In my previous research work I was working on cartesian style printers (Prusa i3 MK3S+). The delta printing contains the same components, tools and interface but the fundamentals work differently. Delta printers, use a vertical rod for movement using steeper motors. By doing so, the extruder is able to move in all directions because each rod moves independently, it is important to note, the rods could only move vertically, up and down [4]. Delta printers could print the same filaments as cartesian printers; however, a delta is ideal in printing ceramics.

One key difference between a plastic (PLA) 3D machine to the one I am building is the extrusion printhead. Usually, a PLA 3D machine heats the bed and print head to melt the plastic and print objects in three-dimensions. However, my extrusion print head will use an air compression system to dispense the clay. An air pressure system is used best because it literally pushes clay out a syringe bottle and as it moves it begins to form the objects shapes. The air pressure system is an idea used by a professor in the United Kingdom, Jonathan Keep [5].

4.1 Programming the printer

The delta printer uses specific requirements that enables it to run correct with minimal errors. I found an opensource document that shows you the basics of setting up a 3D Printer. With the help of GitHub, it made efficient to code the needed parts in order to run. However, since building a 3D printer is different for everyone, I must match my specifications to the code. It isn’t an easy task but may be the most important. Without proper code the printer will not run and the XYZ calibrations would be off. In the code, I will be giving the printer a set of limits that correspond to the height, diagonal rod lengths and extruder radius. Figure 1.1 shows the specific parts that require precise calculations.

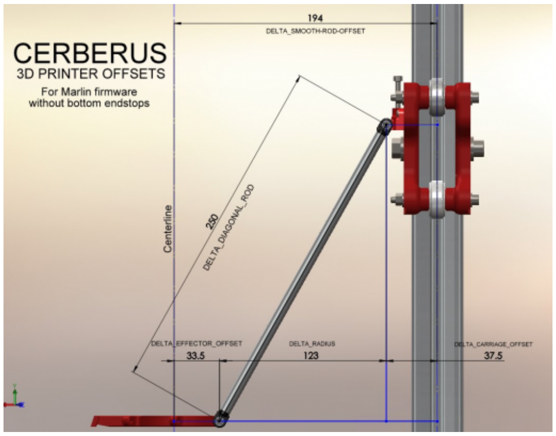

Figure 1.1 [7] *shows a closer look at the lengths I need to calculate for my code.*

4.2 Calibrations

Troubleshooting is a bit more difficult when working on delta printers. Since the printer only uses 3 rods it becomes extremely important to interpret the g code with its proper parameters. Manually calibrating a delta printer is knowing how the g code works. In fact, knowing the code is the only way to solve the issues. This part includes an excessive amount of repetition. By changing the settings of one rod it could potentially change the settings of the other. The source code I intend to use is free and uploaded by professor Keep.

4.3 Clay Assembly

Making the clay requires patience and persistence. I anticipate my concentration will not work at first try. Most designer struggle with getting the correct texture for the clay. In such case, I will work on the clay material using trial and error. The correct concertation is equally important to the coding process. In other words, without the correct concertation the extrusion printhead could potentially get jammed or if it’s to water downed then the object will not be stable. I will also tinker with the air pressure system because the amount of pounder per square inch (psi) the clay needs to successfully extrude is a key part for the entire project.

4.4 Kiln function

The next step is to fire the clay to make it hard and this requires the use of a kiln. The kiln is the most expensive and time-consuming process of all. It usually takes a few days to fire a ceramic, but first you need to glaze the clay with material to help with the burning process. Without the kiln the object will remain as a clay form and ultimately hardness with no use. My objects will have specific heights and dimensions so a small kiln isn't too helpful for my research project. I am looking to use a semi-portable kiln to use at high schools and show students how one works and how to fire ceramic. These tools aren't usually available at schools so showing students how one works would provide them insights with the firing process. In addition, purchasing a kiln will inspire me to build one on my own. Learning how it works is one part, but the mechanics is another. This project has the ability to show me how to make a number of machines related to ceramic 3D printing

5. Planned work and Responsibilities

The summer I plan to take what I know from my previous research experience and apply into my own projects. Much like the Prusa i3 MK3S+ my printing machine will include steeper motors, metal rods and an extrusion print head. I am looking to develop a multifunctional and real time adjustment printer that allows user to easily navigate larger print areas/dimensions. A few tasks will include wiring and connecting the motors, end stops and lcd screen to the Arduino motherboard. An Arduino motherboard is used in a wide range of applications within engineering. For example, these motherboards are used in laser printing/cutting and any application using steeper motors. Hence, the project will show me how an Arduino board works for CNC Machinery, Additive manufacturing, and Robotics. After the code gets successfully saved onto the Arduino board, I upload the Arduino board into a slicer software, called repetier-host. This software is open source and available to anyone that knows how to use it. Learning this open-source slicing tool will inspire me to teach share the knowledge with underrepresented high school students.

The work will result in developing a functional ceramic 3D printer that could potentially be used in a large scale. I intend to create a printer much like Wasp 3D, but with a lower price [6]. 3D printed houses exist today. Companies like WASP have built cranes that allow designers to build 3D houses. For example, the figure 1.2 to the left shows the concept behind a large-scale clay-like printer. I expect to build a small versatile 3D printing machine that could potentially translate to a large-scale printer like the WASP. Cost is highly expensive, a crane at the time costs up to $140,000. In fact, a smaller printer via WASP is nearly $3,000. My machine is intended for scientists and designers in all age groups. Costs should be minimized and any student should be able to access a ceramic 3D printer at affordable prices. My long-term goal is to develop a highly versatile, affordable, multi-material use 3D printers along with compatible kilns and share the knowledge with underrepresented high school students.

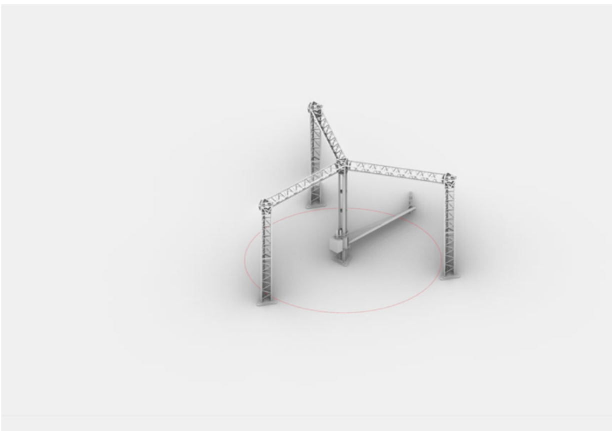

Figure 1.2 *Crane WASP courtesy image by WASP 3D*

6. **Project Timeline: 3 months**

June 2022:

- Find the parts for the three-dimensional (3D) ceramic printer
- Beginning building the frame
- Model a few objects on Rhinoceros 3D software

July 2022:

- Install Arduino and slicing software (Repetier-host) onto my laptop
- Learn how to use code to apply specification for the Arduino board
- Install Arduino onto my laptop
- Upload the code to the Arduino board
- Get familiar with Repetier-host interface
- Connect my printer to the host and update measurements on the slicing software

August 2022:

- Make the clay for the syringe bottle/s
- Set up air pressure system
- Print objects
- Fire the clay using a kiln

7. Resources:

- 3 x NEMA 17-Steeper motors ~ $45.00
- 6 x 12mm Linear motion rods ~ $90.00
- 6 x 12mm bearings ~ $15.00
- 6 x 300mm brass tubes ~ $9.00
- 3 x 1220mm Driver belts ~ $30.00
- 6 x 6mm width Idler Pully ~ $18.00
- 1 x Ramps 1.4 Controller with LCD screen ~ $45.00
- 1 x Arduino Mega 2560 Board ~ $45.00
- 2 x Syringe extruder ~ $30.00
- 1 x 32.8ft PU air hose ~ $15.00
- 1 x inline shut off ball valve ~ $8.00
- 1 x ¼" Compressed Air regulator ~ $15.00
- Dispensing needles ~ $8.00
- 16 AWG Silicone Electrical Wire ~ $15.00
- DC 12V 30A Power Supply 360W ~ $30.00
- 2 x 3D Printer Thermistor sensor 100K ~ $10.00
- 3 x Limit Switch End Stops ~ $12.00
- 1 x Air Compressor ~ $70.00
- 1 x Clay Materials ~ $30.00
- 1 x Glaze ~ $20.00
- 1 x Skutt Kiln KM 818 ~ $2,000.00

Subtotal = ~ $2,560

8. References:

[1] *Intro to Ceramic 3D Printing* – https://3dprinting.com/3d-printing-use-cases/intro-to-ceramic-3d-printing/#:~:text=Technical%20ceramics%20have%20dramatically%20improved,works%20primarily%20with%20classic%20ceramics.

[2] H.L. Marcus, J.J. Beaman, J.W. Barlow, D.L. Bourell, *Solid freeform fabrication-powder processing*, American Ceramic Society Bulletin, 69 (6) (1990), pp. 1030-1031

[3] E. Sachs, M. Cima, J. Cornie, *Three-dimensional printing: rapid tooling and prototypes directly from a CAD model,* CIRP Annals-Manufacturing Technology, 39 (1) (1990), pp. 201-204

[4] Ooi Tian, *What is a delta 3D printer? – Simply Explained*, https://all3dp.com/2/what-is-a-delta-3d-printer-simply-explained/

[5] Keep Jonathan, *3D Delta Printer for Ceramic*, http://www.keep-art.co.uk/Self_build.html

[6] *WASP 3D* - https://www.3dwasp.com/en/3d-printer-house-crane-wasp/

[7] *3D Printer offsets* - https://reprap.org/forum/read.php?1,781167