Ceramic Composite Printing

TEAM 19
MIDTERM REPORT
SUBMITTED TO ME DEPARTMENT

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1. Abstract

This paper provides the most updated details of Team 19's senior design progress this fall semester. The requests of Team 19's sponsor, Dr. Cheryl Xu, are to construct a printer capable of layering ceramic composites reinforced with carbon nanotubes (CNTs) while aligning the CNT's in a manner that best takes advantage of their properties. By themselves, the mechanical properties of ceramics are not ideal for numerous structural applications, but ceramics reinforced with CNTs improve many of these properties such as strength, electrical and thermal conductivity, and temperature stability; this opens up many possibilities for this new composite. Reinforcing the composite with the CNTs is the main challenge due to the difficulty that no previous work has been done in additively manufacturing aligned CNT products, and the challenge of predicting the behavior of CNTs in an electromagnetic field at a certain temperature. The design team will determine the cost benefit analysis, performing material tests with the potential outcomes to find the optimal delivery of the printer, experimenting both with the polymer precursor and with the CNTs to understand the best alignment and curing process, and designing the 3D printer components suitable for these criteria are the major goals for the rest of the semester.

2. Introduction

Additive manufacturing has advanced significantly over time due to the implementation of 3D printing techniques and the numerous materials available to print. In today's market one can now find numerous industrial and desktop printers with 3D capabilities for all possible applications, including but not limited to aircraft and automobile components, fashion and textile products, medical implants, and dental restorations. Demanding markets have driven the introduction of ceramic 3D printers, which represent an important advancement for the manufacturing world due to the complex properties of this composite material. Currently, several ceramic 3D printing devices have been produced. However, in order to stand out from the others, important requirements should be fulfilled including an innovative design, full efficiency, high levels of creativity, and feasibility. With this project we will be implementing the additive manufacturing process and this innovative design aspect by using CNT's to strengthen the ceramic matrix once cured. This introduces another process other than the extrusion of the CNT-ceramic slurry – not only do the CNT's need to be aligned parallel to the platform for optimal property enhancement; the final extruded form must be cured in a manner that will not damage or destroy the CNT's within the matrix. This has required thorough research to discover the best methods for the CNT alignment and curing processes. Once these two methods have been chosen, the design process can progress further to finalize all other necessary components.

3. Project Definition

3.1 Background Research

3D printers have significantly advanced additive manufacturing processes for many diverse industries. Industry estimates indicate that 3D printing industries will be valued at $5.2 billion globally by the year 2020 (McCue). Digitally designed products can now be replicated by adding successive layers of material making up horizontal slices of the product design. This additive process eliminates waste by using only the necessary amount of material, allows unlimited personalization of products, and can reduce manufacturing time and costs when compared to conventional manufacturing methods.

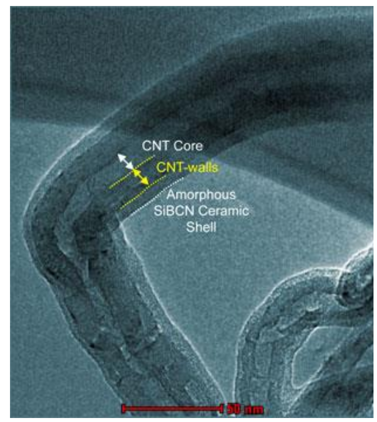

Figure 1 A Composite Structure of Ceramic Material and Carbon Nanotubes.
Image Credit: Kansas State University

Carbon nanotubes have incredible properties that open up a number of new applications for ceramics, while the ceramic composites offer the CNTs protection from mechanical stress, corrosion, and serve as a replacement for metals and plastics (RocCera). Reinforced polymers are used in a number of technical applications and products including sensors, electronics, and fuel cells due to their ability to remain amorphous at extremely high temperatures and excellent bonding properties. An example of such a composite structure can be seen in Figure 1. A number of printer components must be specialized for the ceramic material to ensure that it can be used.

Ceramics have many advantages over metals; hardness values, resistance to wear, and the ability to withstand extremely high temperatures. All these properties are valuable in industry. They give ceramic based parts a longer service time than many metals and take less processing to obtain desirable results. With the introduction of the CNTs into their structures, the reinforced polymers offer a whole new spectrum of uses (Kroll).

This project is strengthening the polymer before it transforms to be the ceramic material by using the alignment of CNTs with an electric field. As far as our research and our sponsors knowledge goes, this particular project has not been experimented with. There are 3D printers that experiment with a wide variety of base materials ranging from metal to silicone. We will be using these prior products that are open source and available to masses to develop our project. The metal or silicon 3D printers are different since they use different materials, but the overall design of 3D printers are similar excluding the extrusion head which needs accommodations depending on the used material. We have access to research papers written about polymer derived ceramics, CNT's, ceramic 3D printing and 3D printing but since there's not a project combining these aspects there is no paper that truly reflects our scope.

3.2 Polymer Properties

The print material for the printer to be designed is a slurry of a polymer precursor, carbon nanotubes, a solvent, and assorted dispersants and sensitizers. The key component of the slurry is the polymer precursor, KiON Ceraset Polyureasilazane. The precursor is a thermosetting polymer sold by KiON Corporation, and can be cured by UV exposure, or by heating to 180-200°C. The Ceraset polymer is designed to convert to a silicon carbide (SiC) based ceramic matrix at high temperatures.

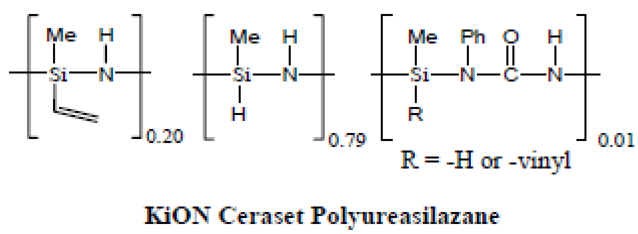

Figure 2 Chemical structure of the polymer

3.3 Needs Statement

Dr. Cheryl Xu is our sponsor for this project. We have finished the define phase of the Six Sigma DMADV (Define, Measure, Analyze, Design, Verify) paradigm, and are conducting material tests to ascertain further design criteria, and to make decisions regarding the most appropriate means of producing the material. Currently, there is no established method or product to additively produce parts consisting of reinforced ceramics, and the current methods is considered wasteful. These sentiments can be summarized into a cohesive needs assessment:

> *There is currently no product or defined method capable of additively manufacturing products made from polymer-based ceramics reinforced with carbon nanotubes.*

3.4 Goals Statement

The primary objective of the project is to have a functioning 3D printer that meets the sponsor's guidelines by the end of spring semester 2014. The printer design will be experimenting with carbon nanotube reinforced ceramic composites. The main goals for fall semester are as follows:

- Perform rigorous cost benefit analyses at each stage of the design process
- Select engineering materials with an understanding on the unique properties and environmental impact
- Investigate the scientific and commercial applications of 3D printed polymer-based ceramics
- Use industry standard 3D CAD tools to assist the design and engineering process
- Create a robust printer design that can be fully implemented in Spring 2015

3.5 Constraints

Due to high customer buy-in, many traditional design constraints will be relaxed for this project. Dr. Xu is willing to devote available lab space to housing the product and will make other resources available to the design team. The constraints on the design of the final product are as follows:

- $5,000 budget for design, material, and fabrication costs
- Product must be able to operate safely in lab environment
- Product must be served by standard mains voltage
- Little to no modification of the print material precursor is feasible
- Build has to be finished by Spring 2015

4. Design and Analysis

4.1 Functional Analysis

This part of the report will be explaining the needs in detail by focusing on each component the team seems fit to identify at this stage in the project.

4.1.1 Printer Specifications

4.1.1.1 Printer Housing and Case

The case of the finished printer will need to serve several purposes: it will need to provide environmental control for the printed part, allow users to interact with the printer safely by insulating them from dangerous energies or materials, and may provide structural support to the entire apparatus. As research continues into the material properties and curing conditions, the needs of the printer housing will further develop, but some necessary properties can be identified at this time. These are listed in Table 1.

Table 1 Printer Case Requirements

Category	***Exemplary Features***		
User Safety	Thermal Insulation	UV Shielding	Fume Control and Exhaust
Environment Control	Convection Fans	Air Filtering	Air Condition Systems
Structural	Self-Leveling Case	Cross Member Supports	

4.1.1.2 Material Delivery and Composite Storage

This portion will require the most attention from the team since this component will be in direct contact with the material desired to be going through the printing process. We need to make this extruder head compatible with where we will be storing the polymer composite that will be ready for printing. Extruder head will have to accommodate any design specs that the team sees fit. This is especially important as we inspect our overall product for the curing of the polymer right after it is printed. We are currently evaluating curing methods and depending on the curing method the extruder head will be requiring additional criteria. If we decide to use heat as a curing method the part where the polymer composite will be should be well insulated so the composite will not transform to its solid state in the storage or the extrusion head.

4.1.2 Additional Subsystems

4.1.2.1 Control Systems

Researching the best microcontroller for Team 19's 3D printer turned up a number of possibilities that could do the job required. When it comes down to it, the Arduino Mega 2560 microcontroller appears to be the best option when compared to the Raspberry Pi Model B+, the smaller Arduino boards, particularly the UNO. With needs such as a friendly user interface, temperature sensors, and control over multiple stepper motors, the microcontroller driving the 3D printer must offer enough room for all inputs and outputs as well as have enough power to drive all of the necessary and desired components without failure. What the Mega offers over its competitors is the amount of pins available for modification – 54 digital input/output pins (15 available for PWN outputs). The Raspberry Pi Model B+ microcontroller was a consideration in the design as well due to the 40 pins available on its board; however, despite having the potential to accommodate all necessary components, its power output showed weak prospects. This would mean that an object being printed would take a much more significant amount of time compared to a board with higher power output. With the Mega 2560, this would be less of a concern.

4.1.2.2 Onboard Display

Dr. Xu would like to the system to be as user friendly as possible. Ideally the onboard display will indicate very important information as the system is in use. This information ranges from temperatures readouts (of the extruder head, polymer composite, and the printer housing if necessary), the time elapsed in printing the object, the capacity of the polymer composite left to extrude, whether more of the composite must be added, and whether or not the process is ongoing or paused. Because so much indication will be so significant to system use, a full LCD display may be in order, perhaps with touchscreen for neatness in order for other options to be implemented.

4.1.2.3 Sensor Packages

After the selection of the 3-D printer, sensors will be implemented onto the printer. A temperature sensor will be a necessity for precautionary and safety purposes. A temperature sensor will ensure that the team is working in the correct temperature range. If the temperature of the curing process is too high then it will cause deformation in the material and possibly cook the carbon nanotubes. If it is not hot enough the efficiency of the print will be slowed down. If this were to happen the sensor would alert the user by making an obnoxious sound or some other way to grasp the user's attention. There are two types of sensors, contact and non-contact. Contact sensors would include thermocouples and thermistors. These would not be ideal because if contact was made with the polymer while curing it may change the shape. Non-contact sensors measure the thermal radiation given off by the heat source, Infrared temperature sensors may be used for this particular project because it has a fast response and it can measure the temperature from a distance. Another item needed would be a camera just to monitor the overall process of the printing. Since the curing of the polymer will be at high temperature the printer or print stage might be enclosed to safety measures, so a camera would be able to provide a close up visual that would be beneficial. A phase sensor would also be implemented and tied with the onboard display. For instance, the phase indicator would let the user know what state the printer is in: printing, curing, pyrolysis. That information would then be relayed to the onboard display giving the user a rough estimation of the time required to finish their final print product.

4.1.3 Material Properties

Mechanical components are crucial at this stage since this will be the decision phase of our project and analyzing our options will yield the best choice overall. We are still consulting our sponsor and mentors for the best selections for the 3D printer. Under the circumstances of the timeline of the project our team decided that it is the best option for us to get an existing 3D printer and retrofit its components to our needs as we see fit. Not all of the components and their factory set specifications will satisfy the needs of this project. Therefore our team will be working on including the most important parts.

One of the components of particular importance is the reserve container for the extruder head. It is important that this reserve not be subject to any of the aforementioned curing methods which would solidify the print material prior to it being deposited onto the build platform. For example, if heat is used to cure the material and the entire printer is in a dedicated enclosure, the polymer precursor could solidify in the reserve container. Therefore the reserve container should be made from a material, e.g. a thermal insulator, which prevents this transformation from occurring

4.2 Design Concepts

Having outlined several of the functional requirements of the various components for the printer design, the team has highlighted some design concepts that represent the synthesis of these requirements and of the team's understanding of the state of the art in additive manufacturing.

4.2.1 Stereolithography (SLA) Printer

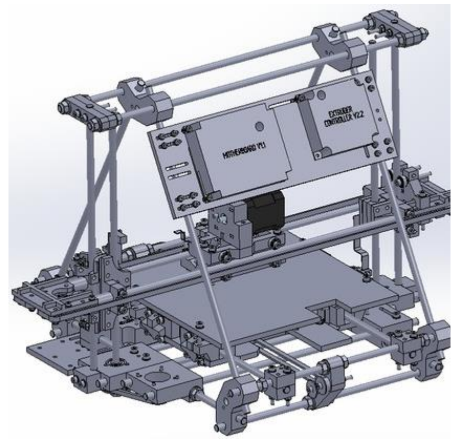
Figure 3 A Reprap Mendel Prusa 3D Printer

Stereolithography is one of the oldest methods of 3D printing, and entails directing an energy source, such as laser light, onto the top of a pool of resin, selectively curing some of the material. The bottom of the pool is movable, and the descent of the print stage allows a fresh layer of resin to be cured, creating the layers of the printed part. The use of SLA technology in the project has several potential benefits: it is a well-established technology with multiple hardware options; there would be no need to design a material flow system; and the method offers high part resolution. After consulting with project sponsors, a few likely pitfalls of the SLA system were highlighted. A primary issue is that an SLA printer requires that the print material be loaded into a reservoir before curing which poses several challenges in the context of the team's design goals: the resin pool is a vector to for impurities in the polymer precursor; the material that is not cured into the final part may exhibit degradation and may require disposal; and the nature of the polymer slurry means that maintenance of a static pool would require the use of dispersant chemicals and other means of ensuring proper mixing.

A variant of the traditional SLA process involves inverting the apparatus, and shining the light through the resin pool onto the print stage. This offers the advantage of utilizing lower-cost components; instead of tracing a high-intensity beam across the top of the pool, a static image can be projected with a common DLP office projector, defining the geometry of each layer. This carries some of the same disadvantages as the traditional SLA printer, but also requires that the resin material be transparent to allow the transmission of light to the print stage.

4.2.2 Semi-Viscous Extrusion Printer

Another means by which the design team can create the 3D geometry is to extrude a semi-viscous (2,000-5,000 cP) material onto the print stage, where it can be cured by any available means. Extrusion can be achieved by the use of compressed air, mechanical compression as in injection molding; and by the use of precision syringe pumps. This design has the potential to be a simple, low cost means of applying the polymer to the print stage. Potential challenges include the control over the flow rate of the extrusion process and modifying the material to meet viscosity requirements.

4.2.3 Modified Inkjet Printer

Another potential design is use technology borrowed from inkjet printing to deposit material to the print stage. An inkjet printer works by drawing a liquid from a cartridge and pressurizing the material until it passes through one of several micro-nozzles in the print head. This over-pressure can be induced by a boiling a portion of the material so that the expansion drives out a droplet of matter. Additionally, a piezoelectric buzzer may use high frequency vibration to pressurize the droplet sufficiently enough to print.

Advantages in using modified printer components lie in the availability of low-cost salvaged components, high print resolution, and built-in control of the material deposition process. Challenges include the actual control of modified components such as printer drivers and motor encoders, along with the combination of the desired print material with commercially available printer heads.

4.3 Evaluation of Designs

After outlining several design concepts, some of them were compared with existing alternatives to address which option fits better customer and technical requirements. All these evaluations represent good alternatives that could be implemented; however, they still need to be tested to determine if they are indeed the best options to implement on the project design. Thus, these results are subjected to change depending on the testing’s findings.

In order to do the previously described comparisons, decision matrices will be used. Each alternative/factor will be scored from zero to five, using five to describe the most important parameters. Then each value is multiplied by its relative importance percentage, and the alternative with the highest total is selected as the most appropriate. The component decision matrices are shown on Appendix 6.

4.3.1 Material Delivery

As it was pointed out before, the material delivery represents a crucial component for the development of the project. Important criteria must be taken in account before deciding what type of extrusion head is going to be used. Table 2 shows four different options and the parameters selected to compare each of these alternatives. The specifications shown in Table 2 are taken from commercially available dispensers, as a result, size and capacity parameters will vary depending on which model of dispenser is chosen and how is it assembled. According to the parameters chosen, a nozzle-based extrusion head should be used; however, cost analyses and experimentations must be performed before making a final decision.

Table 2 Material Dispensers Specifications

	Pressure	*Fluid Viscosity*	*Material Capacity*	*Min. Shot Size*	*Working Temp.*	*Maintenance*	*Orifice Diameter*
Syringe	10–20 psi	30,000cps	3-30 mL	30 µL	65°C	Easy	1-4 mm
Nozzle	20 -50 psi	< 20 cps	> 0.5mL	140 µL	Up to 250°C	Detailed Process	20-80 µm
Pipette	-	1-150 cps	37 µl	30–300pL	160°C	Easy	30–80 µm
Cartridge	-	≈290 cps	> 0.5 mL	5pL – 0.5 nL	Up to 50°C	Easy	10-80µm

4.3.2 Curing Method and Alignment

There are several curing alternatives that will be taken in consideration for the curing process. Some of these alternatives include Ultraviolet light, laser, and heat. Experimentations will be performed in order to find out which curing technique works best for the project purposes.

4.3.2.1 Ultraviolet Light

Ultraviolet light as a curing process has important advantages including a fast room temperature curing, and it requires less space and equipment than convection ovens. UV curing is based on a photochemical reaction, which can be used to dry the polymer. There are many benefits from using the UV curing method. For instance, conventional heat drying works by evaporating the solvent and causes the material to shrink in volume. In UV curing, there is no solvent to evaporate so there is no loss in volume. Also, UV curing would speed up the curing process compared to the heating method in Table 1.

Testing is underway to determine the relative time to cure under different lighting conditions. Test parameters will include the wavelength of the UV source, overall output wattage necessary to induce curing, and how the addition of CNT to the polymer slurry affects the UV transparency of the print material.

This technique also has some limitations that must be taken in consideration at the time of selection. The primary limitation of a light curing method is that the material to be cured must fulfill wavelength and intensity specifications. Table 3 shows a comparison between three different UV light alternatives.

Table 3 UV Light Alternatives

Alternative	*Power*	*Voltage*	*Current*	*Wavelength*
UV lamp	10-200W	85-265V	900-1500mA	400-410nm
UV LED	60-80 mW	4-4.3V	350-600mA	370-380nm
UV Flashlight	1000-1200 mW	3.8-4.3V	7001200mA	390-395nm

4.3.2.2 Laser

Lasers are considered high power sources, which are ideal for modifications on the material's surface and they produce narrowly focused energetic beams compared to the ultraviolet light.. They are able to produce changes on the surface without affecting the material's properties. The use of lasers provide important advantages that might be beneficial for the CNTs reinforced ceramic material such as chemical cleanliness, and it is a non-contact process. Since the laser technology provides a high energy density laser beam, the surface of the material can be heated at a quicker speed compared to other types of curing methods.

They have good curing properties, however, they are dangerous and expensive. The main concern if is this kind of curing alternative will end up damaging the carbon nanotubes contained on the ceramic composite. Currently, the team is planning on testing a 10 Hz pump type IV laser, which has a wavelength range between 400-2300 nm and an output power that ranges between 2-20mJ. This will help to analyze the behavior of the material in front of this type of light source, and compare the results with other type of alternatives to determine which one fits better the necessities of the material.

4.3.2.3 Heat

There are several types of methods that can be used to heat the precursor material to its curing temperature range. Three of these alternatives include using a hot plate, a convection oven, or using infrared technology. For curing and drying processes, convection ovens are considered the best options for products with complex shapes. Since convection ovens transfer heat through the air, any surface exposed to the air will absorb the heat evenly. This leads to a uniform heat distribution, which is not possible with infrared technologies. Additionally, when using a convection oven, the color surface coating does not affect the ability of the material to absorb the heat. On the other hand, coatings with reflective properties when using infrared technologies can inhibit heat transfer. Table 4 shows a comparison between the three previously mentioned heat curing alternatives.

Table 4 Heat Curing Methods

Features	*Hot Plate*	*Convection Oven*	*Infrared Tech.*
Even heat distribution		✓	
Not sensitive to reflective properties		✓	
Low cost source	✓	✓	✓
Uses less energy for surface heat			✓
Well-controlled low-intensity heat			✓
Intensity can be easily adjusted			✓

Heating the material is a possible means of inducing the curing of the polymer precursor. With the exception of advection, there are three means by which the material can be heated to its curing temperature range. If heating is selected as the final means of curing the polymer, care will need to be taken to not damage the CNTs or to induce pyrolysis prematurely.

Our team experimented with the hot plate to figure out a general timeframe. Our tests yielded an understanding of the temperature time relationship for our polymer. We used the pipette to form the droplets and placed these droplets on a glass and we realized that pipette was not very reliable in forming samples to be tested. Below table and graph depicts what we tested and the exponential correlation between temperature and time

Table 5 Hot plate test data

Temperature (Celsius)	*Delta T (seconds)*	*Diameter (mm)*
150	*391*	
160	*271*	*5.32*
170	*211*	*7.5*
180	*121*	*6.97*
190	*89*	*6.74*

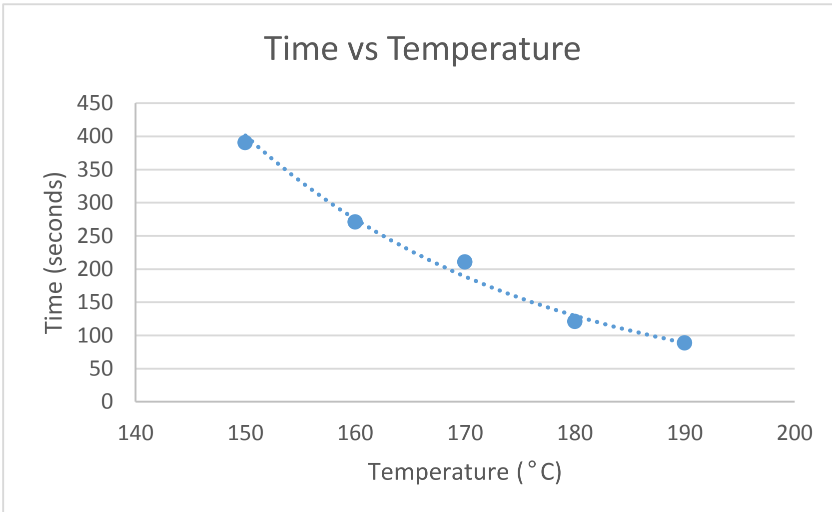

Figure 4 Graph representing the polymer solidification

4.3.2.4 Visible Light

Wavelengths of visible lights have a better distribution than those from ultraviolet light. A larger distribution of wavelengths generally broadens the necessary range of wavelength for curing; however, visible light only have low energy, making this method very poor for curing. Even though the application of visible light as a curing method might not be a proper technique for the project purposes, it has important advantages including the strong light penetrance, it is safe to the human body, and it is a relatively inexpensive radiation system.

4.3.2.5 Alignment Field

CNTs are polarizable particles, therefore an electromagnetic field can be used to induce alignment of the CNTs within the polymer matrix. Aligning the CNTs improves the polymer's properties in the direction of alignment and allows for these properties to be better controlled as compared with randomly oriented CNTs in a polymer matrix. Soon, testing will be conducted by varying the field strength & application time of the electromagnetic field, while maintaining a constant frequency. Past experimental studies have shown that there is a strong correlation between an increase in each of these individual parameters and the alignment of the CNTs. The team has discussed using either an electric coil or a magnet to generate the aforementioned electromagnetic field.

4.3.2.6 Cooling

In order for our CNTs to align in their optimal form the temperatures should be in the range of 100-200 K. Looking at Figure 2 below, the optimal temperature range would be around 90-100 K. When extruding the polymer mixed with the carbon nanotubes the carbon nanotubes will be misaligned unless there is an electromagnetic field present. Looking at the graph, there is a ratio of the magnetization that is perpendicular and parallel to the average orientation of the nanotubes. The magnetization is higher when parallel to the orientation of the nanotubes. When it is parallel it reflects improper geometry. From the graph it compares this ratio of magnetization to the optimal temperature for alignment. The higher the parallel magnetization the lower the ratio will be, so around 0.85 is when the parallel magnetization is at its highest. This is how the team has decided the optimal temperatures for aligning the carbon nanotubes. Hence, there is an obstacle present; in order to cure the polymer the temperatures need to be around 100-200°C, which is a drastic change from 100K. We will be further experimenting with this parameter to make sure it will be meeting the sponsor requirement and physics laws.

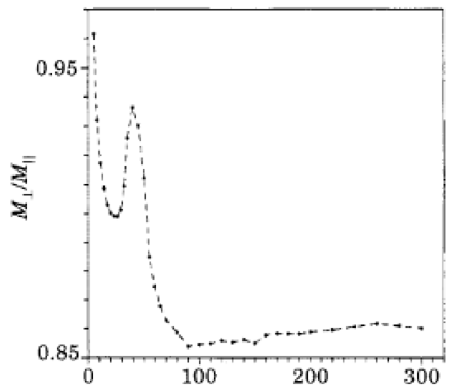

Figure 5: Magnetization Energy Ratio
Image Source: (Byszewski and Baran)

4.4 Criteria & Method

Selection criteria were compiled by referring to the Voice of the Customer (VOC), visualized in the Quality Function Deployment (QFD) shown in Appendix 4. The QFD diagram, otherwise known as the House of Quality, represents the efforts of the design team to quantify and rank the competing desires and requirements of the customer.

The House of Quality is divided into three important sections: Customer requirements, technical requirements, and targets. Customer requirements list all the features that the sponsor requested; technical requirements list all the constraints that must be satisfied, and difficulties that must be overcome in order to fulfill customer requirements. Finally, the targets' section involves concluding alternatives that might be used to satisfy technical requirements, and fulfill customer requirements.

The relationship between each of the listed features, for all of the sections, is clearly defined by using figures that distinguish whether the relation is positive/negative, or strong/weak. Additionally, all of the features are ranked by order of relevance, determining which ones are the most important for the development of the project.

According to the matrix's results, there are four factors considered critical to quality in terms of customer requirements. These factors are: Producing a smooth surface on the final product, stay under budget, use of an alignment field for the CNTs, and safety. For the technical requirements, determining the appropriate levels of temperature to work with is the most important factor at this moment.

The information shown on this matrix is subject to change, depending on what the sponsor requests, and what results are obtained during the testing process.

4.5 Selection of Optimal Design

By synthesizing the requirements and preferences of the project sponsor with the advantages and challenges inherent in each design concept, the design team was able to rank the design concepts using a decision matrix.

Weight Factor	Printer Design Concept Ranking							
	Cost	Material Efficiency	Material Suitability	Resolution	Curing Time	Flexibility of Design	Ease of CNT Alignment	Sum
Alternatives	**0.08**	**0.17**	**0.23**	**0.07**	**0.15**	**0.15**	**0.15**	**1**
Stereolithography	3	2	1	4	3	2	2	2.14
Modified Inkjet	4	4	3	3	3	3	3	3.25
Extrusion	2	4	4	2	3	3	4	3.4
Projected Light SLA	4	2	1	3	3	3	2	2.3
Powder Jet Binding	3	3	0	2	2	3	1	1.79

5. Methodology

The team began the project by reviewing the sponsor's requirements to ensure that we will design or modify a printer to meet these requirements. The team is currently conducting background research on the unique properties of CNTs to gain a better understanding of the materials' advantages and limitations. This research will provide the team with knowledge on how to effectively incorporate CNTs into use as a new print medium. Additionally, the team will examine open source software for the Arduino microcontroller platform as a hardware to PC interface.

Next, key material properties will be determined for the various components of the printer. Once these properties are established potential material choices that are suitable for the design's operating parameters will be identified. A materials selection matrix will completed on these material candidates and focus on optimizing the design according to the constraints placed by the sponsor.

Computer Aided Design (CAD) software will be used to model the printer design which will assist in the design and engineering process by enabling the team to make prompt changes to the design if issues arise. Furthermore, a cost benefit analysis will be completed on the design to evaluate the design on criteria including but not limited to cost impact and the amount of reduced materials. We aim to complete the design phase by the end of this academic semester.

5.1 Project Schedule

Great care will be taken by the team to ensure the timely submission of all deliverables; additionally, industry tools such as Microsoft Project, Dropbox, and Outlook Events will be employed to coordinate team meetings and communicate the status to project stakeholders. The current project schedule can be seen in the Gantt chart depicted in Appendix 1.

5.2 Assigned Resources

A resource allocation report can be seen in Appendix 2, which outlines the total amount of work completed on the project and the estimated amount of work that remains. The individual assignment of team members to tasks can be reviewed in Appendix 3. Using Microsoft Project it is possible to check the resource allocation areas to check for overloaded team members, and conflicting periods of resource use. Currently, the only assigned resources are the team members, but as the project progresses money, consumable materials, and lab equipment may be managed in the same way.

5.3 Work Breakout Structure

1. Analyze Material Properties
    - 1.1. Chemical makeup of polymer precursor
    - 1.2. Curing options
2. Select Hardware Components
    - 2.1. Delivery
        - 2.1.1. Test delivery method with material
        - 2.1.2. Interpret data
        - 2.1.3. Modify system
    - 2.2. Frame
        - 2.2.1. Analyze selected printer frame
        - 2.2.2. 3D model frame
        - 2.2.3. Check design envelope for added components
        - 2.2.4. Establish routing for wires and material feed
    - 2.3. Positioning
        - 2.3.1. Examine printer capability
        - 2.3.2. Recalibrate with hardware additions
        - 2.3.3. Add output to display and PC interface
    - 2.4. Alignment
        - 2.4.1. Test permanent magnet, electromagnet alignment, and coil
        - 2.4.2. Incorporate selected method hardware
        - 2.4.3. Manage EM field effects on printer frame
    - 2.5. Curing
        - 2.5.1. Test UV and heat curing
        - 2.5.2. Interpret data
        - 2.5.3. Design curing assembly
        - 2.5.4. Incorporate into frame/print head
3. Interface
    - 3.1. PC Graphic User Interface
        - 3.1.1. Examine existing PC interface
        - 3.1.2. Determine changes to be made
    - 3.2. Onboard display and controls
        - 3.2.1. Implement sensor inputs to controller board
4. Documentation
    - 4.1. Create operation manual for users
    - 4.2. Write safety data, Material Safety Data Sheets
5. Installation

6. Conclusion

This multidisciplinary project is to design and construct a 3D printer capable of additively manufacturing a material composed of carbon nanotubes, ceramic, and a precursor polymer created by Team 19's sponsor and advisor Dr. Xu such that it will simplify the manufacturing process involving the material and make it possible to make essentially any component out of this material imaginable. The niche of this project is to make the polymer derived ceramic stronger by involving the CNTs due to their properties and creating and curing a reinforced ceramic base with the CNTs properly aligned. To do this we are contacting several faculty members who have significant expertise in CNTs ceramics and 3D printing, including Dr. Wei Guo and our sponsor, Dr. Yong Huang, of UF, and discussing with them the project. We will design the components of the 3D printer, keeping in mind various design aspects and prioritizing the integrity of the CNTs within.

Cost benefit analyses will be conducted to ensure that the end product will deliver maximum value to the sponsor, and decision matrices ranking all of the options and their weighted value to the project will be completed for finalization of each component. Fully understanding the materials and the precise specifications of the sponsor/advisor/mentors is very important when considering the components to be used. Also understanding the alignment of CNTs, how they combine with the ceramic, how they are effected in pyrolosis, and incorporating these three areas into an additive manufacturing field is going to be extremely challenging. The final product will provide a new means of manufacturing CNT reinforced ceramic polymer composite material.

Having the opportunity to work with such a complex material is making for an incredible lifetime experience, and the products obtained from the final product of this senior design project will have many real-world applications in the future. This project and its members are going to work diligently and with a strong sense of creativity and productivity to solve the obstructions present throughout this project while on the way to meeting the major self-defined goals set forth.

7. References

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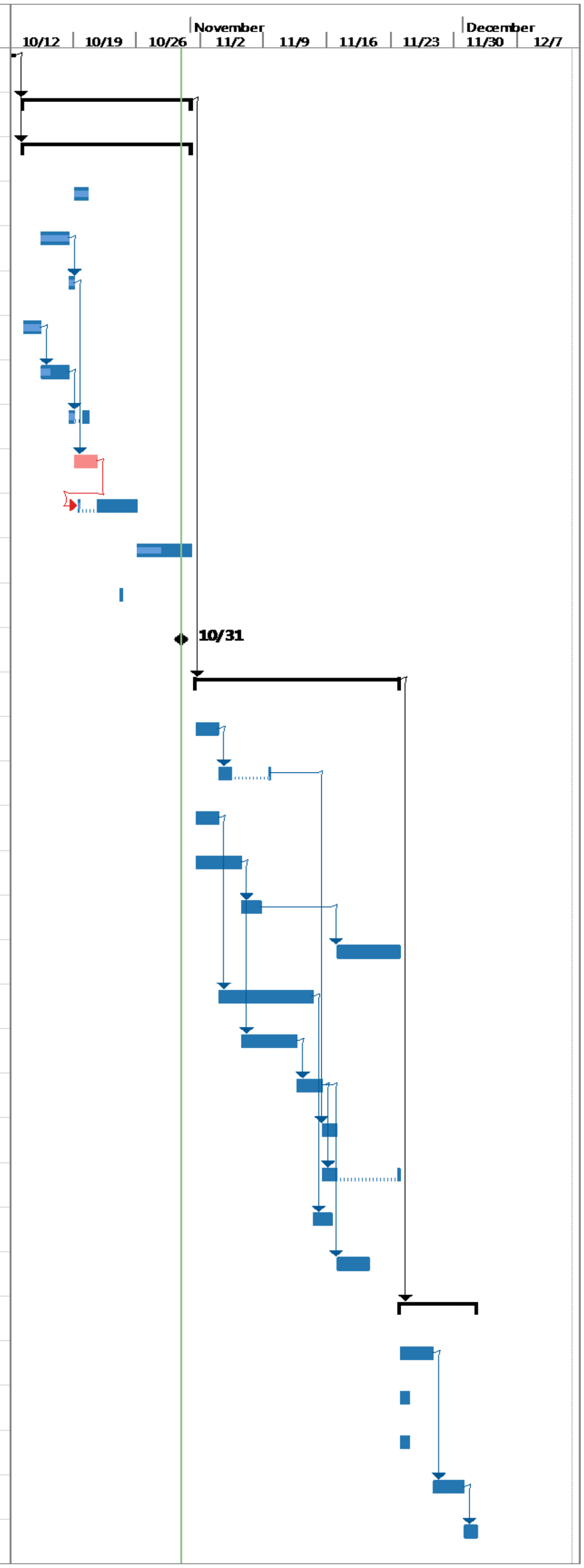
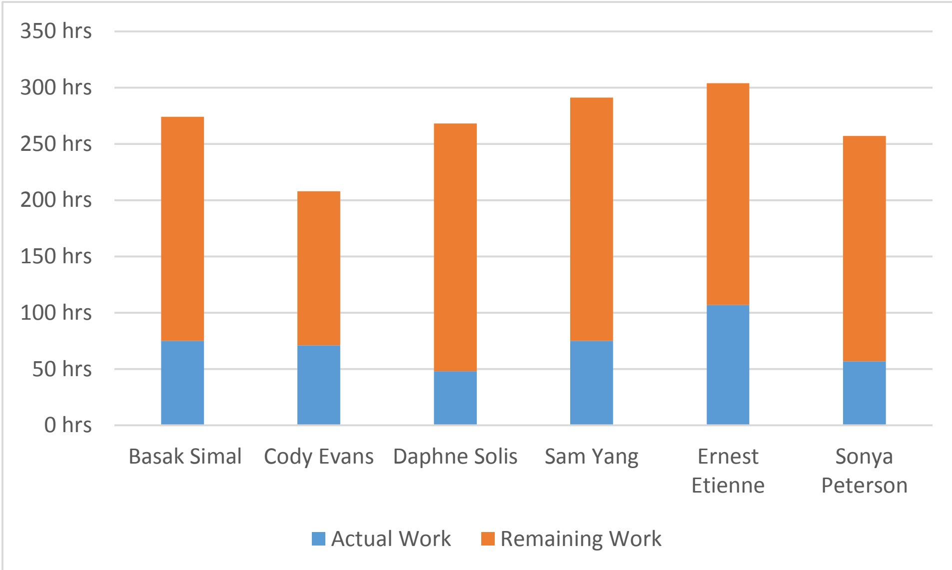
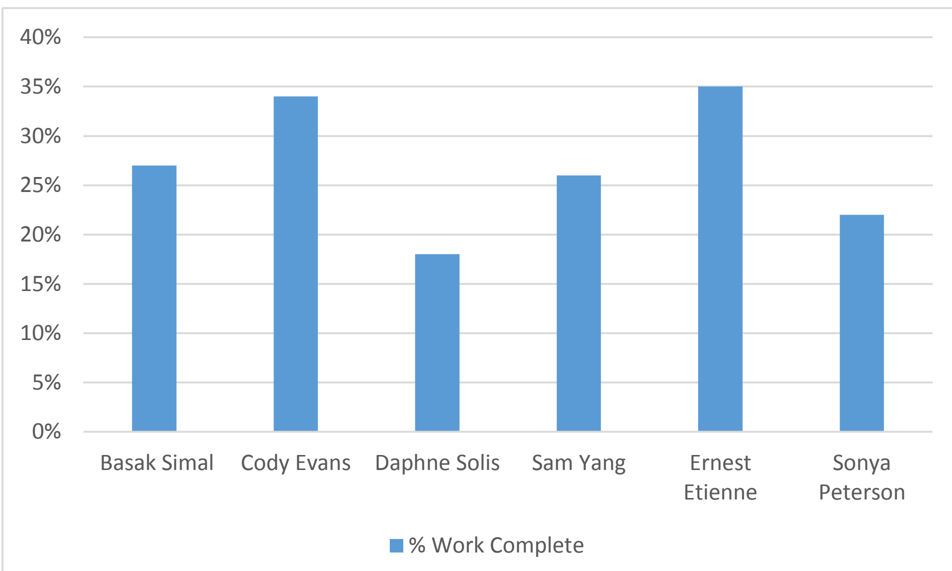
Appendix 1 Gantt Chart

ID	Task Name	Duration	Start	Finish
6	**Define**	**2.02 wks**	**Mon 9/29/1**	**Sun 10/12/14**
11	**Measure**	**2.75 wks**	**Mon 10/13/**	**Fri 10/31/14**
12	**Define Goals/Objectives**	**2.75 wks**	**Mon 10/13/**	**Fri 10/31/14**
13	Define working temperatures	1.6 days	Sat 10/18/14	Mon 10/20/14
14	Set material parameters	2.4 days	Wed 10/15/14	Sat 10/18/14
15	Extrusion Head Constraints	0.8 days	Sat 10/18/14	Sat 10/18/14
16	Examine policies on LN2, UV, and Laser	1.6 days	Mon 10/13/14	Wed 10/15/14
17	Research UV Capability	2.4 days	Wed 10/15/	Sat 10/18/14
18	Establish Cure Times	1.6 days	Sat 10/18/1	Mon 10/20/14
19	Estimate Alignment Hardware Envelope	2 days	Sat 10/18/14	Tue 10/21/14
20	Compare Commercial 3D Printer Opt.	4 days	Sun 10/19/14	Sat 10/25/14
21	Update midterm report	5.4 days	Sun 10/26/14	Fri 10/31/14
22	Co Sponsor Meeting	1.5 hrs	Fri 10/24/14	Fri 10/24/14
23	Submit MT Report	0 days	Fri 10/31/14	Fri 10/31/14
24	**Analyze**	**3.57 wks**	**Sat 11/1/14**	**Sun 11/23/14**
25	Curing Testing	3 days	Sat 11/1/14	Mon 11/3/14
26	Finalize curing method	1.4 days	Tue 11/4/14	Sun 11/9/14
27	Inkjet selection	3 days	Sat 11/1/14	Mon 11/3/14
28	Select alignment hardware	5 days	Sat 11/1/14	Thu 11/6/14
29	Obtain alignment equipment	2 days	Thu 11/6/14	Sat 11/8/14
30	CNT alignment testing	6.2 days	Mon 11/17/14	Sun 11/23/14
31	Inkjet printer acquisition and testing	9 days	Tue 11/4/14	Fri 11/14/14
32	Alignment testing	5.7 days	Thu 11/6/14	Wed 11/12/14
33	Finalize alignment results	2 days	Wed 11/12/14	Sat 11/15/14
34	Set design envelope curing	2 days	Sat 11/15/1	Sun 11/16/14
35	Set design envelope alignment	2.2 days	Sat 11/15/14	Sun 11/23/14
36	Set design envelope printer head	2 days	Fri 11/14/14	Sun 11/16/14
37	Marry printer head to 3d printer system	3 days	Mon 11/17/14	Thu 11/20/14
38	**Design**	**1.3 wks**	**Sun 11/23/14**	**Tue 12/2/14**
39	Begin CAD Work	3.2 days	Sun 11/23/14	Thu 11/27/14
40	Prepare purchase orders	1 day	Sun 11/23/14	Mon 11/24/14
41	Begin Product Data Management tasks	1 day	Sun 11/23/14	Mon 11/24/14
42	Define BOM	3 days	Thu 11/27/14	Sun 11/30/14
43	Expense Report	1.6 days	Sun 11/30/1	Tue 12/2/14



Appendix 2 Resource Allocation Report





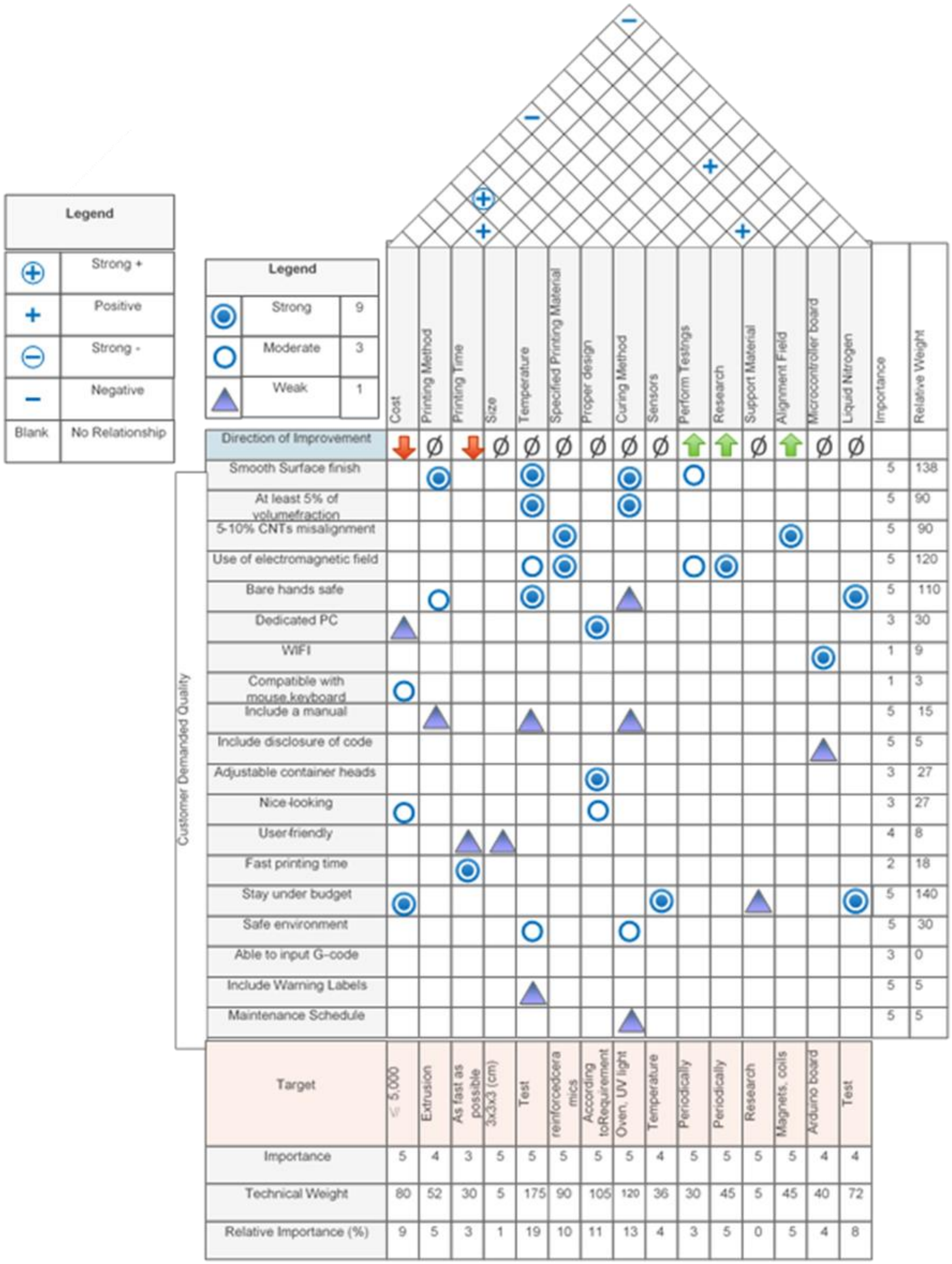
Name	Start	Finish	Remaining Work
Basak Simal	Wed 9/10/14	Thu 12/11/14	199 hrs
Cody Evans	Wed 9/10/14	Thu 12/11/14	137 hrs
Daphne Solis	Wed 9/10/14	Thu 12/11/14	220 hrs
Sam Yang	Wed 9/10/14	Thu 12/11/14	216 hrs
Ernest Etienne	Wed 9/10/14	Thu 12/11/14	197 hrs
Sonya Peterson	Wed 9/10/14	Thu 12/11/14	200 hrs

Appendix 3 Resource Allocation

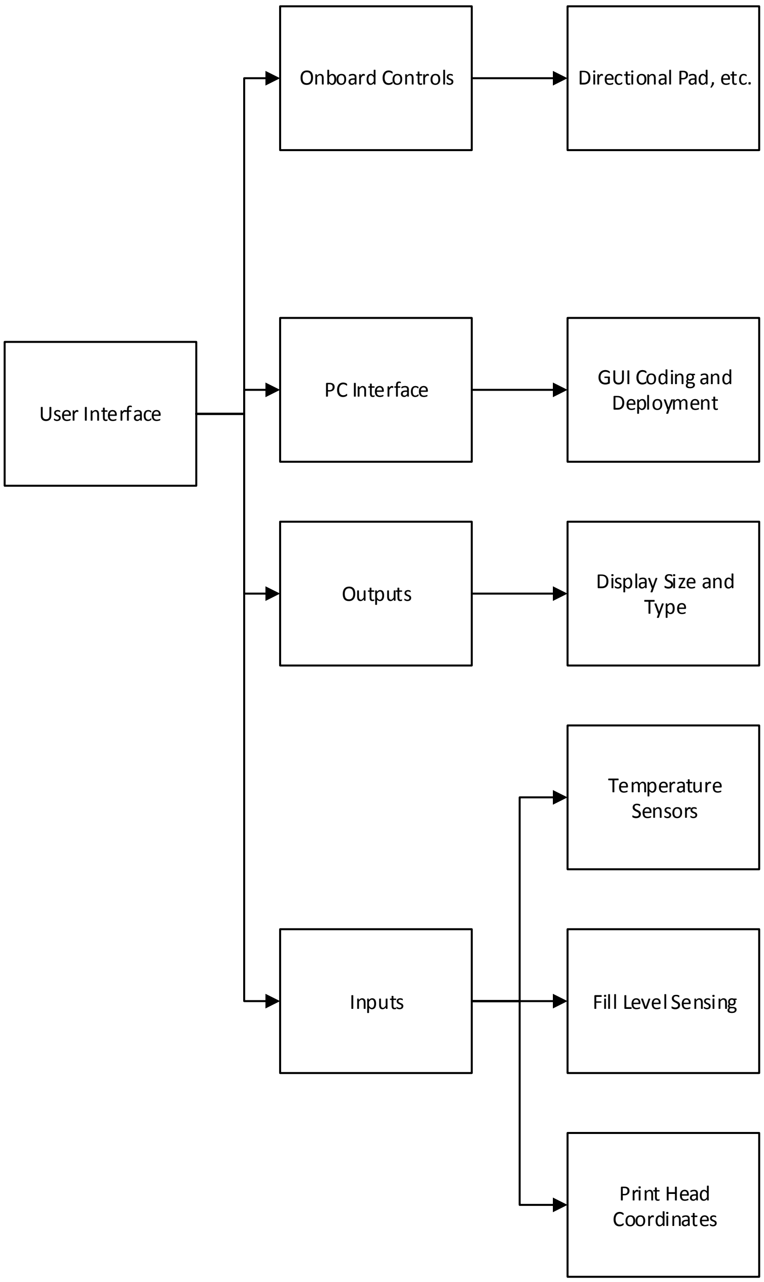
Resource Name	Work	Resource Name	Work
Basak Simal	206 hrs	**Daphne Solis**	192 hrs
Begin Project	*0 hrs*	*Begin Project*	*0 hrs*
Establish Team	*2 hrs*	*Establish Team*	*2 hrs*
Complete and Deliver Code of Conduct	*3 hrs*	*Complete and Deliver Code of Conduct*	*3 hrs*
Conduct Needs Assesment	*8 hrs*	*Conduct Needs Assesment*	*0 hrs*
Research Competition Rules	*0 hrs*	*Assess Competition Viability*	*8 hrs*
Assess Competition Viability	*8 hrs*	*Meet with Sponsor*	*38 hrs*
Needs Assessment Deliverable	*0 hrs*	*Analyze VOC*	*16 hrs*
Meet with Sponsor	*38 hrs*	*Examine State of the Art*	*8 hrs*
Analyze VOC	*16 hrs*	*Examine Example Blue Prints*	*24 hrs*
Draft Product Specifications	*8 hrs*	*Check kit specs against goals/reqs*	*24 hrs*
Update Needs Assessment	*8 hrs*	*Define BOM*	*5 hrs*
Update Code of Conduct	*8 hrs*	*Expense Report*	*16 hrs*
Submit Project Spec Report	*0 hrs*	*Prepare final documentation*	*24 hrs*
Query machine shop on tooling and material options	*3 hrs*	**Sam Yang**	231 hrs
Examine Example Blue Prints	*24 hrs*	*Begin Project*	*0 hrs*
Check kit specs against goals/reqs	*24 hrs*	*Establish Team*	*2 hrs*
Submit Prelim. Design to Sponsor	*8 hrs*	*Complete and Deliver Code of Conduct*	*3 hrs*
Prepare final documentation	*24 hrs*	*Research Competition Rules*	*4 hrs*
Cody Evans	170 hrs	*Assess Competition Viability*	*8 hrs*
Begin Project	*0 hrs*	*Meet with Sponsor*	*38 hrs*
Establish Team	*2 hrs*	*Analyze VOC*	*16 hrs*
Complete and Deliver Code of Conduct	*3 hrs*	*Draft Product Specifications*	*8 hrs*
Research Competition Rules	*4 hrs*	*Examine policies on LN2, UV, and Laser*	*16 hrs*
Assess Competition Viability	*8 hrs*	*Establish Cure Times*	*16 hrs*
VentureWell Application	*3 hrs*	*Estimate Alignment Hardware Envelope*	*8 hrs*
Meet with Sponsor	*38 hrs*	*Compare Commercial 3D Printer Opt.*	*8 hrs*
Draft Technical Questionnaire	*4 hrs*	*Design Custom Print Head*	*24 hrs*
Analyze VOC	*16 hrs*	*Begin CAD Work*	*32 hrs*
Draft Product Specifications	*8 hrs*	*Conduct FEA, and other design checks*	*24 hrs*
Update Needs Assessment	*4 hrs*		
Update Code of Conduct	*8 hrs*		
Examine Example Blue Prints	*24 hrs*		
Check kit specs against goals/reqs	*24 hrs*		
Ernest Etienne	214 hrs		

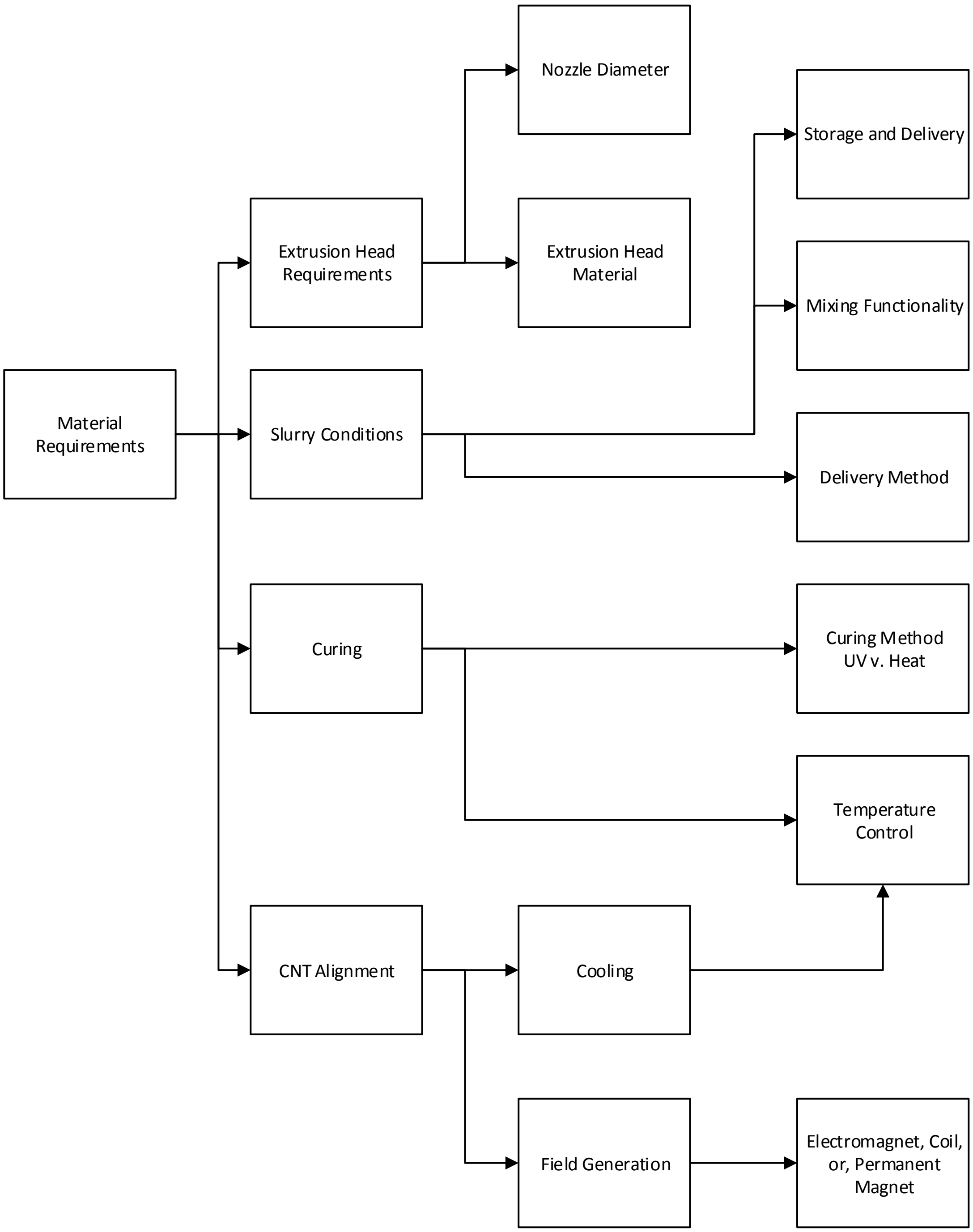
Begin Project	*0 hrs*	
Establish Team	*2 hrs*	
Complete and Deliver Code of Conduct	*3 hrs*	
Assess Competition Viability	*8 hrs*	
VentureWell Application	*0 hrs*	
Meet with Sponsor	*38 hrs*	
Analyze VOC	*16 hrs*	
Meet with Matl. Expert Jinshan	*3 hrs*	
Define working temperatures	*16 hrs*	
Set material parameters	*24 hrs*	
Extrusion Head Constraints	*8 hrs*	
Examine policies on LN2, UV, and Laser	*16 hrs*	
Begin CAD Work	*32 hrs*	
Conduct FEA, and other design checks	*24 hrs*	
Sonya Peterson	203 hrs	
Begin Project	*0 hrs*	
Establish Team	*2 hrs*	
Complete and Deliver Code of Conduct	*3 hrs*	
Assess Competition Viability	*8 hrs*	
Meet with Sponsor	*38 hrs*	
Analyze VOC	*16 hrs*	
Examine State of the Art	*8 hrs*	
Research UV Capability	*24 hrs*	
Compare Commercial 3D Printer Opt.	*8 hrs*	
Examine Example Blue Prints	*24 hrs*	
Check kit specs against goals/reqs	*24 hrs*	
Prepare final documentation	*24 hrs*	

Appendix 4 House of Quality



Appendix 5 Work Breakdown Structure Diagram




Nozzle Diameter
Storage and Delivery
Extrusion Head Requirements
Extrusion Head Material
Mixing Functionality
Material Requirements
Slurry Conditions
Delivery Method
Curing
Curing Method UV v. Heat
Temperature Control
CNT Alignment
Cooling
Field Generation
Electromagnet, Coil, or, Permanent Magnet

Appendix 6 Component Level Decision Matrices

Weight Factor / Alternatives	Extrusion Head Design Criteria							
	Working Pressure	Fluid Viscocity	Material Capactity	Min. Shot Size	Temp. Resistance	Cleanability	Orifice Diameter	Sum
Alternatives	0.15	0.25	0.15	0.06	0.25	0.11	0.03	1
Syringe	4	2	4	2	2	5	4	2.99
Nozzle	5	3	2	3	5	3	3	3.65
Pipette	0	1	1	1	4	5	3	2.1
Cartridge	0	2	2	1	2	5	3	2

Weight Factor / Alternatives	Heat Alternatives					
	Heat Dispersion	Material Volume	Surface Finish	Cost	Speed	Sum
Alternatives	0.25	0.1	0.25	0.25	0.15	1
Hot Plate	2	3	2	4	2	2.6
Convect. Oven	5	3	4	4	4	4.15
Infrared Tech.	2	3	3	4	3	3

Weight Factor / Alternatives	UV Light Alternatives					
	Output Wattage	Voltage	Current	Wavelength	Temperature	Sum
Alternatives	0.2	0.15	0.15	0.25	0.25	1
UV lamp	2	4	4	4	0	2.9
UV LED	3	3	2	3	0	2.15
UV Flaslight	4	3	3	3	0	2.55