Ceramic Composite Printing

Team 19
Interim Design Report

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Team Biography

Ernest Etienne - ME

Ernest is a senior at the FAMU-FSU College of Engineering, and is expected to graduate with his B.S. in Mechanical Engineering in May 2015. He is interested in material processing and is working on obtaining his certificate of specialization in Mechanics and Materials.

Cody Evans - IE

Cody is a senior at the FAMU-FSU College of Engineering, and is expected to graduate with his B.S. in Industrial Engineering in May 2015. After graduation he plans on working in industry, and is interested in statistical quality control, project management, and business simulation.

Sonya Peterson - ME

Sonya is an FSU senior mechanical engineering student expecting to graduate in 2015. It is still uncertain where she would like to see herself following graduation, she hopes to progress the movement for a greener future and construct better living standards for every person on the planet to benefit from.

Basak Simal - ME

Basak is an FSU student studying Mechanical Engineering and she will be graduating in Spring 2015. She has not claimed a specialty but has studied thermo-fluids and manufacturing.

Daphne Solis - IE

Daphne is an FSU senior student with a dual major in Industrial Engineering and Actuarial Sciences, and she will be graduating in 2015. She is interested on the fields of quality engineering, industrial systems, and engineering management.

Sam Yang - ME

Samuel is an undergraduate student enrolled at Florida State University, and he will be graduated with a Bachelor of Science in Mechanical Engineering in Spring 2015. He is specializing in the aeronautics field and is a member of the AIAA.

Acknowledgements

Much of what has been accomplished this semester would not have been possible without the knowledge and experience graciously shared with Team 19 from numerous professors and College of Engineering staff. Team 19 would like to thank each and every one of these individuals for their contributions to the team's progress.

First and foremost, the team's very own sponsor **Dr. Cheryl Xu** has been the strongest support of all. She has opened the Ceramic Composites Manufacturing Lab operating under the Mechanical Engineering Department to Team 19 to use for their senior design project and gave them the opportunity to incorporate additive manufacturing with a senior design group.

Dr. Jinshan Yang, one of Dr Xu's graduate students, was very helpful to the team and helped identify the materials characteristics and gave important insight in understanding how the materials are projected to behave when mixed. He also supplied help in the lab while testing the materials.

Xiangzhen Sun, another one of Dr. Xu's graduate students, helped understand the CNT alignment and their interaction with electromagnetic field closely.

Jerry Horne from HPMI has been extremely helpful in the areas of 3D printer design and construction. He has built numerous printers himself for various purposes and will prove to be one of the team's greatest assets by the project's completion.

Dr. Yong Huang from the University of Florida has provided information taken from his own experiences from 3D printing to the team's efforts. With so many possible methods of extrusion available and with such a unique material to extrude, the issue of how to best extrude the ceramic polymer composite was resolved in a discussion.

Dr. Wei Guo from the National High Magnetic Field Laboratory (NHMFL) has been a bottomless resource for information concerning all matters of the project; from the in-depth explanation of creating an electromagnetic field for the CNT alignment to the Class IV laser he made available to the team for pyrolysis testing.

Brian Mastracci, one of Dr. Guo's graduate students, must also be commended for giving his time and patience in showing the team a method they could follow for laser curing.

Sam Taira from the AME Center was a connection recommended by Dr. Guo. He is a great guide who assisted the team with obtaining the best simulation methods and software for alignment and curing methods.

Abstract

This paper provides the most updated details of Team 19's senior design progress during this fall semester. The request of Team 19's sponsor, Dr. Cheryl Xu, is to modify an existing 3D printer in order to make possible the printing of a novel material called carbon nanotubes reinforced ceramic composite. Additionally, the carbon nanotubes (CNTs) contained on the polymer must be aligned in a manner that best takes advantage of their properties. The mechanical properties of standard ceramics are not ideal for numerous structural applications; however, ceramics reinforced with CNTs improve many of these properties, including strength, electrical and thermal conductivity, and temperature stability. As a result, this opens up many possibilities for the success of this novel composite. Reinforcing the polymer with the CNTs is the main challenge that the team is facing, due to the deficiency of information regarding additive manufacturing that implements aligned CNTs, and the difficulty of predicting the behavior of the CNTs exposed to an electric field. It is known that applying an electric field at high alternating current voltages can align the CNTs; and according to the calculations, the electric field strength necessary is approximately 7000 volts per meter. The team implemented decision matrices in order to determine what component would be used for the CNTs alignment, and to decide on what kind of method would be used to extrude the material. In addition, a decision matrix was also implemented to choose the TAZ 4 3D printer, which is the printer that will be retrofitted in order to meet the sponsor's requirements. The team will be conducting different experiments next semester to be able to reach the goal of extruding a polymer reinforced with carbon nanotubes.

I. Project Overview

In this section Team 19 will develop an overview of the entire project and the breakdown of the scope as understood by the team. Some of these points have been changing throughout the semester; nevertheless, the sections detailed below include the most updated information based on the team's meetings with both the sponsors, and instructors.

A. Customer Requirements

Dr. Xu is the project sponsor and the customer to whom the printer will be delivered. This 3D printer will print a proprietary polymer composite, and will gain augmented material characteristics through the addition of carbon nanotubes (CNTs). Listed below are the requirements the sponsor provided.

- $5,000 budget for design, material and fabrication costs
- Operate safely in a lab environment
- Little to no modification of the polymer composite
- Repeatability and resolution of printed parts similar to the parts produced by established methods of 3D printing
- Sensors to allow monitoring the status of the print job, and record vital experimental data
- Print times on the same order of magnitude as established 3D printers.

B. Scope

The project scope was initially defined as designing and building a 3D printer that would print a novel material mixture consisting of a polymer precursor, reinforced with CNTs. In response to faculty feedback, the team decided to purchase an existing 3D printer and retrofit it to meet the desired goals. Hence, the final project scope will be to retrofit an existing 3D printer that will be capable of extruding a polymer precursor reinforced with CNTs. Additionally, the polymer precursor will utilize UV curing and alignment of the CNTs via an applied electromagnetic field.

C. Goal

The goal of the team project is modifying an existing 3D printer to fit the customer's needs. The project revolves around being able to preserve the material characteristics while solidifying the liquid polymer slurry. The end goal of the project is having a working prototype of a printer capable of curing the polymer precursor with embedded CNTs.

D. Objectives

Listed below are some of the core project objectives, as determined from meetings with stakeholders as well as brainstorming as a team throughout the semester:

- Test several extrusion methods to determine the optimal method of extrusion of the polymer precursor to the print stage
- Test CNT alignment methods in order to develop an electromagnetic field that can sufficiently align the CNTs in the liquid material
- Test several curing methods to determine the optimal method of curing the polymer precursor to cure and solidify the liquid polymer
- Modify the extrusion head part of the 3D printer for permitting the best use of the extrusion method to preserve the polymer precursor material characteristics
- Modify the print bed to allow CNT alignment at where the composite is projected to be cured
- Implement sensors as indicated by the team's sponsor
- Make calculations and CAD drawings for each of the components that need modification, if needed.

E. Challenges

Working with a novel material is already considered a challenge for the team since it has not been easy to find information related to the team's project. Additionally, sponsor's requirements slow down the project completion, because supplementary information needs to be researched. Some of the most outstanding challenges that team 19 has been facing, and will be facing in the future are the following:

- Since this is the first time that this material has been mixed with CNTs for this kind of application, it has been very difficult to define acceptable parameters
- Since this material has never been mixed for printing purposes, predicting the behavior of the polymer is almost impossible, as a result many experiments must be done before being able to print a piece of material
- Some problems have arisen when purchasing components, due to the hobby based level of the devices that the team's project needs.
- Defining a project scope has been challenging due to the multiple changes on the project description
- The team should be able to print a basic geometrical shape (square, triangle) by the end of Spring 2015.

II. Design and Analysis

This section aims to describe the design considerations of the final product, working at the component-level. Design concepts and further analysis will be explored in detail to justify the use of each component.

A. Function Analysis

1. Mechanical

a) Printer

The 3D printer represents one of the main components for the development of the team's project. In order to avoid time-consuming tasks regarding the design and construction of a printer, the team decided to purchase a commercially available one. Nevertheless, this component needs to be modified in different ways and therefore it embodies a great mechanical challenge. The changes that the team will be performing will allow the best possible extrusion of the printing material, a good environment for the curing process, and an accurate design for the alignment of carbon nanotubes.

b) Extrusion Head

This component is going to make sure that the polymer composite will preserve its characteristics and composure throughout the entire printing procedure while being able to control the amount extruded. It also has to allow bigger particles in it such as the multi walled CNTs, which will allow the polymer composite to have strengthened characteristics once they are uniformly aligned.

c) CNT Alignment Unit

This component will be attached to the print base to align the CNTs within the polymer composite matrix. This device will be functioning after the extrusion, and before the curing of the current polymer layer. For the purposes of alignment the team will be implementing an electromagnetic field.

d) Curing Method

This component utilizes an array of UV spectrum emitting LEDs to cure the liquid polymer after the CNT alignment stage is complete. By mounting the array near the extrusion head, it will be possible to cure the material in the path in which it is being extruded.

2. Electrical and Computing

a) Sensors

The team's sponsor requested the use of several sensors to control the printing process, and monitor it in order to ensure a proper process follow up. Some of these sensors include a camera to visually monitor and record the printing process, an infrared thermometer to measure the temperature of the printed material, and light meters to measure and calibrate the UV curing equipment.

b) Curing Method Control

This component intends to control the duration and the intensity of the UV curing system. Additionally, it will provide feedback to the operator regarding the current settings. This control component will be integrated by using a microcontroller board, which will be explained later in this section.

c) CNT alignment

The team will perform further experimentation regarding the electric field application for the CNTs alignment in the coming phases of this project. According to some research that the team has made, and the knowledge of the advisors, CNTs are very difficult to align due to the presence of intermolecular Van Der Waal's forces. However, one option that the team is considering for this alignment is generating an electric field between two electrodes, which would be allocated parallel to each other very close to the print stage.

d) Microcontroller Board

This component will be coupling the data coming from the sensors, then it will be storing these data points in the dedicated computer that the team has inside the lab. It will also monitor the curing process and its pulsing method to deliver the appropriate amount and intensity of LED light.

e) Dedicated Computer

The team's sponsor agreed on the team getting a computer devoted to managing the data coming from the printer and the appropriate control and modeling software needed to run the printer. This component will be sourced from the college surplus supply and will be used solely for controlling the printer.

B. Design Concepts and Further Analysis

Since the project involves the use of an already existing product, which the team will be retrofitting, the design concepts Team 19 has been working on are not the design for the entire printer, but of different configurations of the separate parts that the team will be assembling. Below are the detailed descriptions and explanations of the parts to be retrofitted.

1. Mechanical

a) Extrusion Head

This component's design will implicate the use of a syringe pump. When Team 19 met with one of the mentors, Jerry Horne, he suggested that starting with syringes that have smaller cross sectional extrusion areas would be more manageable compared to the nozzle, due to precision and built-in means of storage for the polymer composite. It would also make the transfer of the polymer composite easier during the testing and the prototype phase.

One of the design ideas for this particular component is shown in Figure 1. This is a version of what the end component will resemble. A stepper motor coupled with a gear set, which corresponds to a specific gear ratio that mandates and regulates the adjustments to viscosity of whatever material is being printed. This picture is using the gear ratio 7:1 for a paste-like print material, however, the polymer composite that the team's sponsor is providing has a much smaller viscosity, which is equivalent to that of the water; thus the gear ratio will be reduced. The gear is then attached to a push rod that behaves similarly to precision syringe pumps that team 19 has been using for testing purposes. This calculated and coded push extrudes the raw material out of the syringe outlet to the print base in a controlled manner.

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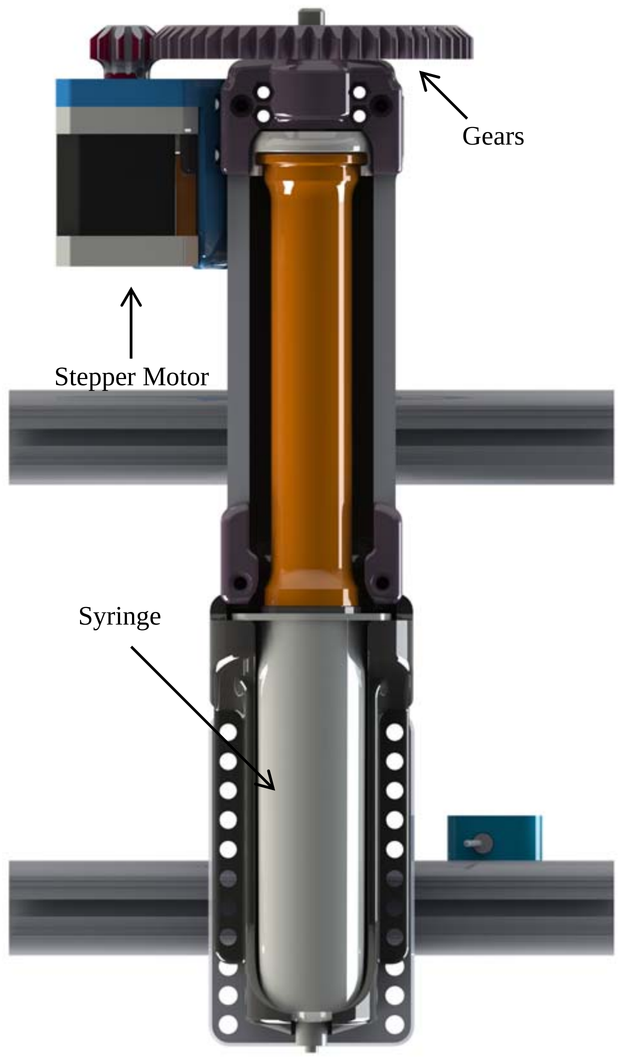

Figure 1: Extrusion Device Prototype

b) CNT Alignment

For the CNT alignment part of the project, Team 19 will be focusing on applying an electric field through the polymer composite that is being printed to align the CNTs as they are passed on to the print stage. The schematic describing how this step will be looking like is presented in Figure 2. Electrodes will be supplying the electric field strong enough to properly align the CNTs inside the polymer slurry. Team 19 is still trying to find out how strong this field needs to be, and how much strength can be achieved by implementing alternate methods such as uncommon earth magnets or coils. A minimum of approximately 70 % accuracy is desired by our sponsor, consequently the team is evaluating what material should be used to deliver the best and the most accurate results while coupling the polymer composite with CNTs, as the printing job is ongoing. In Appendix C there is a CAD model to depict how this electric field will be applied within the printer for visualizing this application clearer.

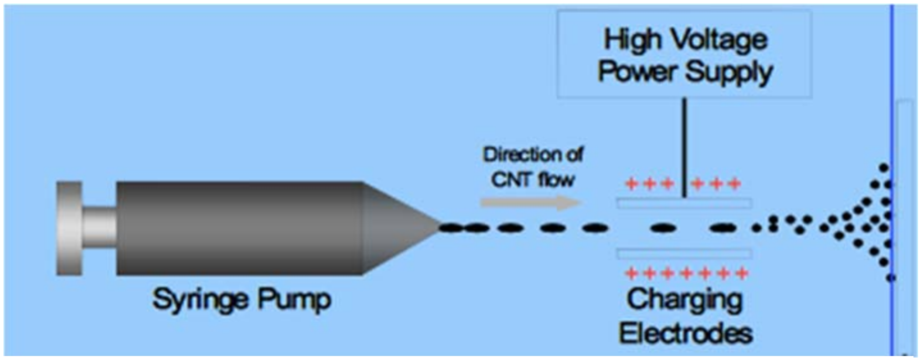

Figure 2: CNT alignment with electrodes

c) Curing Method

Team 19 decided to use UV LEDs, nevertheless, the design of the array of LEDs has not been determined yet. Several different ideas for the application and placement of the LED array have been discussed between the team, and with both sponsor, and advisors. Appendix A shows the specification of each of the LEDs that the team purchased for the array assembly. Each of these LED lights has a wavelength of 405 nm, a DC current of 30 mA, and a Voltage of 3.4 V. Additionally, Appendix C shows an LED array that the team will possibly be implementing for curing purposes. The design ideas for the base of the array will be manufactured with aluminum scraps from the Mechanical Department Machine Shop, and the LEDs will then be introduced on the aluminum base. Some ideas that the team took into consideration, include: a circular plate, which is the LED array with another circle in the middle cut out to allow enough clearance for the extrusion head; 2 or 4 squared LED arrays positioned across or around the extruder head, so the curing procedure does not interfere with the curing procedure; or plate arrays beside the 3D Printer. Additional specifications, and calculations regarding the LEDs are shown on Appendix B.

d) 3D Printer

Figure 3: Lulzbot TAZ 4

The team and the team sponsor decided to purchase a commercially available 3D printer to be retrofitted. This component will allow the team to begin with the testing process in depth, and to accurately solve the problem that will arise throughout the project development.

Lulzbot TAZ 4 is the printer Team 19 decided to purchase, and it is shown on Figure 3. In order to decide what 3D should the team buy, many parameters were taken into consideration.

The most important selection criterion for the team was having open source availability for both hardware and software. Another important feature that the team took into consideration was the delivery time of the printer itself, because some of the other 3D printer alternatives would take more than a month to arrive, which would have slow down the project noticeably. Additional parameters that help on the final decision were the ease of assembly, and the tools' kit that came with the printer package. This tool kit is significant advantage for the team, because they are required for the modification of the 3D printer. Finally, a LCD screen that outputs the state of the 3D printing process will also come with the printer package. Since this particular product has this feature as requested by our sponsor, the team will have more intergraded sensors within the 3D printer system and less manual sensors that would need to be coupled with the microcontroller and the dedicated computer to make sure that the data is compiling.

2. Electrical

a) Microcontroller

The 3D printer that Team 19 decided to purchase will come with a RAMBo (RepRap Arduino-compatible Mother Board) board. Figure 4 shows a clear image of how this kind of controller looks. This board is fully capable for handling the tasks being delegated, including fundamental printer action. Since open source design within the software is used, the alteration of the coding depending on the project needs, is possible. However Team 19 decided to get an Arduino Mega 2560 in case it is necessary to control different functionalities that are new to the system. The main reasons why the Arduino microcontroller was selected over other alternatives were its reasonable price and its easily understandable setup.

To operate reasonably well with all this equipment, Team 19 members will be doing a lot of research in order to understand and regulate this component as good as possible.

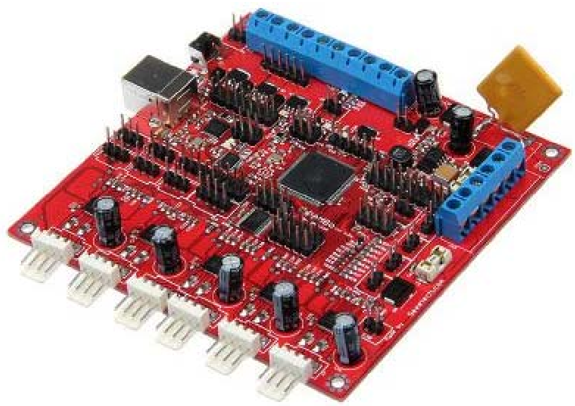

Figure 4:RepRap Arduino Mother Board

b) CNT Alignment

The team will purchase an AC power supply in order to produce the required voltage of the electric field needed for the CNTs alignment. This power supply will be required, because the standard wall outlet voltage of 110 V is not sufficient voltage to align the CNTs. The decision of implementing and AC power supply rather than a direct current power supply was taken after reading multiple research papers, which showed that alternate currents are better for inducing CNTs alignment. The team will have to integrate the power supply to work-in parallel with the printer extrusion process. At this moment, the specific power supply that the team will be using has not been determined; however, further analysis will be done in order to choose the one that fits better the project needs.

c) Sensor Coupling

The team will be utilizing some sensors that the sponsor requested in order to measure accurate temperature at a certain moment, measure UV light intensity, and a camera that will allow the user to monitor the complete printing process. To have these sensors working, team 19 considered two different alternatives. In the first place, the sensors can be connected to the microcontroller board that is already purchased. If this option were implemented, it would be necessary to add different codes to the already existing printer code, to address the sensors that the team needs to implement, besides receive and store the data collected by these devices. The second idea was order sensors able to work independently from the microcontroller, and the printer. By doing this, the team would be able to purchase better quality components, and therefore receive more accurate information from the printing process. All members of the team, and the sponsor agreed with the second option, because it seemed more reasonable to buy better quality components in order to have a precise data collection, than to purchase basic components that will not gather the most exact information, and will need additional codes in order to be implemented with the help of a microcontroller board. Most of the sensor decisions will be finalized this week, and some will be ordered later this week so the team will be able to use them by the beginning of next semester for appropriate experimentation and data collection.

d) Dedicated PC

The dedicated PC represents a significant part for the development of this project, because this device is the one that will be displaying the camera recordings, and it is here where the team will be able to notice important mistakes, and other factors that cannot be addressed with the naked eye. Additionally, it will allow the storage of microcontroller setup information, and the storage of data coming from the different sensors. It is important to mention that in order to start the printing process, it is necessary to install a software on the computer, related to the 3D printer. As a result, a dedicated PC will be indispensable, because without it, the printer will not be able to work.

C. Evolution of Designs and Selection of the Optimum

This section summarizes the different parts of this project, and how have they evolved from the beginning of the semester, until the current date. In general, many alternatives have been researched and some experiments have been performed in order to find out what are the optimum selections for this project.

This project initially began because the Mechanical Engineering Department wanted to introduce the manufacturing field into their program. Therefore, the idea of having a project involving additive manufacturing resulted. Later on, the project gained a clearer definition, which involved the design and construction of a 3D printer. In order to achieve this, the team was introduced to the ASME IAM3D Challenge, which was a completion that had to do with designing a 3D printer, and thus it was considered appropriate for the purposes of the Mechanical Engineering Department. Then, the team was set, and the sponsor was elected. Time passed, and Dr. Xu suggested the modification of an existing 3D printer in order to be able to print a novel material mixture that she was using as research matters. At this moment, the team is working on getting this project working with the sponsor's specifications.

1. Evolution of Design

a) Curing Method Evolution

Team 19 studied two different options that could be used for the curing process of the printing material. These choices include UV light curing, and heat related curing. Heat curing is divided into two different areas, which are convectional heating, and laser. On the other hand, the UV curing method can be divided into LEDs, and UV lamp, among others. These can be seen on Figure 5, where the curing methods are decomposed into their varieties.

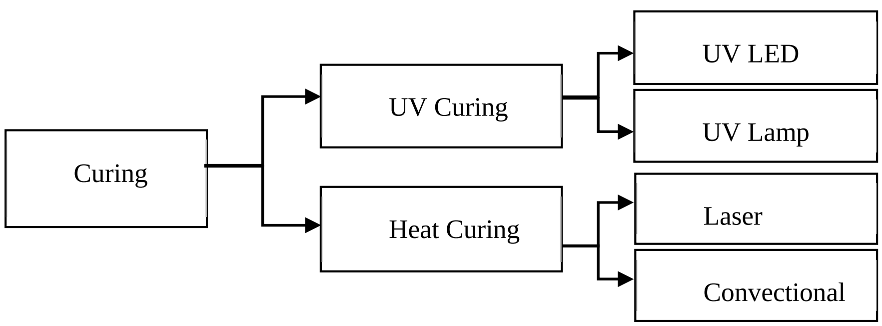

Figure 5: Various methods of curing

Additionally, a decision matrix was employed in order to compare the most relevant parameters of each of the methods to determine what kind of curing process the team should implement. By doing this, the team ensures that the final decision will be the best possible choice. This decision matrix is shown in Table 1 below.

Table 1: Decision Matrix for Curing Selection

	Cure Time	Placement Flexibility	Availability	Area of Effect	Envelope Size	Safety	Total
Weight	0.25	0.1	0.1	0.2	0.2	0.15	1
UV LED	3.5	5	4	3	5	4	3.375
UV Lamp	3.5	2	3	3.5	3	5	2.675
Laser	4	4	3	1	4	2	2.7
Heat	3	3	3.5	4	2.5	3	2.7

The curing time factor will definitely be an important consideration for the team's project. At this moment, the team does not have clear how long will it take to cure this kind of printing material, however, the team is intending to reach a curing time similar of that of already existing 3D printers.

The placement of the curing systems is something else that the team had to consider at the time of deciding which method would be better for the 3D printer chosen, and the printing material that will be utilized. As it is visible on Table 1, the UV lamp scored poorly on the placement flexibility parameter, because it is bulkier compared to all other alternatives; so that would be an example to explain the meaning of placement flexibility.

Area of effect is another important factor, since Team 19 decided that a margin of error must be given for the treated area in order to be more successful with preferably no missed spots. If the area of effect is small there can be errors and all the spots may not be treated the same. This led to laser scoring very poor on this criterion as the laser beams are much more focused compared to the other possible selections. Envelope size was also another important criterion since it would be more feasible to deal with small components and again give Team 19 flexibility to place the curing system where the team thinks is better. UV LED scored very well on this criterion since its incorporation would be consisting of an array of LEDs each 3 mm in diameter. Lastly, safety is always a parameter that Team 19 should be thinking about, because this product will be in the lab.

In addition, Team 19 experimented with heat using the polymer composite without the CNTs. A pipette and a hot plate were used for this purpose. Results yielded that the best time Team 19 achieved with the hot plate was around 80 seconds (See Figure 6). Even if Team 19 does not have a set parameter for curing time, Team 19 knows that this value is not very desirable. This caused us to abandon using heat as the curing method.

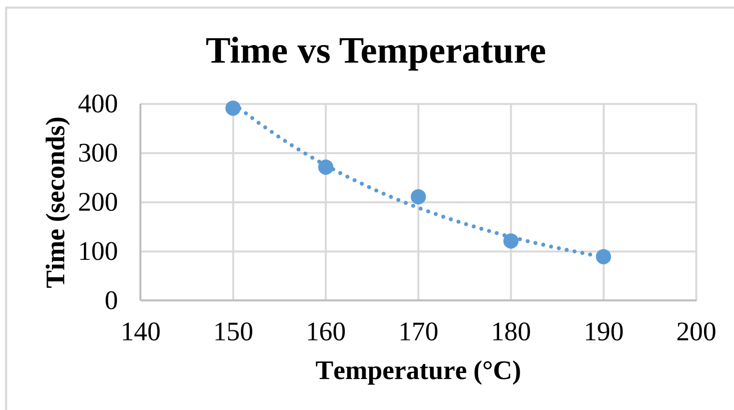

Figure 6: Hot plate curing results

The team tried to run experiments with a laser Team 19 had the chance to borrow from our advisor Dr. Guo, but there were several complications. Team 19 was told that the outlets at the college were not similar or adequate compared to the machinery coming from the NHMFL. Safety procedures in between buildings would also be different; Team 19 would need to be trained specifically for operating the laser equipment as well.

Due to mobility and the theoretical effectiveness of the UV LEDs Team 19 decided to proceed with the UV LED alternative for the curing method.

b) Extrusion Head Evolution

Several alternatives were taken into consideration at the time of deciding which extrusion mechanism would be more favorable for the project purposes. Based on a lot of research, and experts opinions, team 19 ranked the different options by using a decision matrix shown on Table 2.

Table 2: Decision Matrix for extrusion method

	Variable Flow	Fluid Viscosity	Material Capacity	Min Shot Size	Temperature Resistance	Cleanability	Total
Weights	0.15	0.25	0.2	0.2	0.1	0.1	1
Syringe	5	4	4	5	5	5	4.55
Nozzle	4	5	5	4	5	3	4.45
Pipette	3	3	2	1	3	4	2.5
Cartridge	4	1	4	3	1	2	2.55

Having a variable flow and being able to control input flow is the criteria where Team 19 had some trouble with during the ongoing testing phase. Being precise and having an accurate way of outputting the same amount of material is important for an extrusion procedure. Viscosity of the fluid is the most important factor to determine what extruder head to use, because the polymer composite will need to preserve its properties, and this viscosity is not going to be similar to melted ABS most printers operate with. Cartridge gets the lowest mark due to its possibility to clog due to the micro nozzles, which use heat to activate the fluid inside it. Material capacity is important since having to refill the materials before the printer finishes printing will be counterproductive. Minimum shot size was another difficulty Team 19 discovered during the testing. Using the pipette, the droplets created were too big, which Team 19 theoretically knows will affect the curing time significantly. With the pipette, Team 19 had some control but not enough to mandate how small the droplet size could be.

Temperature resistance was added to the matrix in case Team 19 decided to proceed with heat for a curing method. Finally, cleanability is on the decision matrix since the shelf life for our polymer composite is around 3-5 days and in case of residue, the extrusion mechanism must be easy to be cleaned.

With these criteria and possible selections in mind, Team 19 will be moving forward with the syringe and needle, or nozzle setups. Team 19 will be further experimenting with these methods via testing in order to fully decide what method would be better to implement.

c) Printer Selection Evolution

After the project scope changed, the team came together and decided what 3D printer should be purchased. Team 19 was initially looking into a generic hobby printer with a lower price range, nevertheless, the team's sponsor Dr. Xu increased the preliminary budget and informed that it would be better to have a high quality printer that will be more durable to the upcoming modifications. All members of the team researched different 3D printers and Team 19 voted within the team to construct a decision matrix chart, which can be seen in Table 3.

Table 3: Decision matrix for 3D printer selection

	Sponsor Preference	Open Source System	Availability & Lead Time	Value Added Features	Fit and Finish	Extruder Head Clearance	Total
Weight	0.1	0.15	0.15	0.10	0.20	.30	1
Lulzbot KitTAZ	5	5	4	2	5	5	4.55
Aurora	4	4	4	4	5	3	3.9
Mini Kossel	2	5	5	2	2	3	3.2
Maker Gear	3	3	4	4	3	5	3.85

Open source hardware and software is also listed as a criterion since Team 19 will be taking it apart to attach the custom extruder head to fit the project needs. Availability and lead-time was an important factor, because the team did not want to wait any longer to get to the 3D printer. The value added features parameter is listed to point out different features that could be needed in the future. The fit and finish criterion refers to the exterior appearance of the 3D printer. One of the sponsor's requests was to have a professional and nice look on the printer, as a result, that point was taken into consideration.

Extruder head clearance is considered the most important criterion since Team 19 will be retrofitting the extruder head and there should be enough free space to permit any design Team 19 may go forward with. After revising all these parameters, and all of the available options, the team decided that the best choice was purchasing the Lulzbot KitTAZ. Refer to Table 3 to see final results obtained.

After getting clearance from purchasing, the department was ready to order KitTAZ but Team 19 and the sponsor were contacted by the department to indicate that the price of both KitTAZ and TAZ was decreased due to Cyber Monday sales. Therefore, Team 19 decided to purchase the TAZ 4, which is an advanced model of the kitTAZ. The TAZ 4 was not considered at the beginning due to the high price it has, however, when the price decreased there were no more doubts about this 3D printer. Refer to Appendix A to see the TAZ 4 specifications.

2. Final Design

The final design mainly consists of a commercially available 3D printer that has both open source software and hardware so Team 19 can change the components, as the team needs to. Main changes to the purchased 3D printer will be the extruder head and the CNTs alignment system. Extruder head will need to accommodate to the characteristics of the polymer composite, which would have a completely different consistency from what the printer is designed to print. The design Team 19 has in mind is focusing on the control of the extrusion of the slurry at a controlled speed and with the finest resolution while the extrusion procedure is unobstructed and can perform well.

The design will utilize the housing and the controls of the existing 3D printer and extrude the polymer composite onto the print stage through the extrusion mechanism. The CNTs alignment unit attached to the printing stage will be working while the print head is printing materials, this way the CNTs are projected to be aligning within the polymer composite before the curing phase starts. The curing process is projected to be flashing in pulse mode to fully transform the polymer composite matrix that is in liquid state to its solid state after printing each layer. This will ensure that the polymer matrix would not be cured to its solid state while it is still above the extrusion head. After the extrusion, alignment and curing for one layer, the method will be repeated until desired shape is formed.

D. Detailed Design and Design for Manufacturing

This part of the report is only applicable to some of the retrofitted parts that Team 19 has to design for the maximum efficiency and effectiveness of the scope. The designs include the LED plate that ensures light reaching to the printed surface, and the print base attachment for supplying the electric field. Refer to Appendix C to see detailed CAD drawings of these parts.

There are a couple of design concepts for the placement of the LEDs. One of the main ideas is to setup an array of LEDs. This will call for an LED plate like a printed circuit board. LED (light emitted diode) emits light; hence the name, however most of the electricity in an LED becomes heat rather than light. LEDs run at high temperatures, if they get hot enough it will decrease the efficiency of the wavelength generated or it may have a thermal runaway. Since, the LEDs will be adjacent to each other there is a higher risk that some of the LEDs may overheat. To prevent this, a LED plate can be manufactured with heat sinks or fins to transfer the heat via conduction, convection, and radiation.

Concerning the extrusion mechanism, when operating a syringe pump, it is usually done manually. However, when applied to a 3D printer it will need to be able to operate automatically. A stepper motor with a pinion and gear or worm gear will need to be constructed, so that as the gears move, it will be able to extrude a droplet of the precursor on the print stage. The amount extruded and placement would be controlled by the microcontroller.

In addition, an electric field will be implemented in order to align the CNTs. A design for the placement of the field will also be necessary. The alignment can be done in two ways for this project. The first way is done magnetically and the other way is by an electric field. As suggested by Dr. Guo, an electric field would be more suitable for this application. For the CNTs reinforced precursor to align, it will need to pass through interdigitated alternating current electrodes.

III. Risk and Reliability Assessment

A. Inclusion of CNTs

First of all, it is important to mention that there is very little work and research done regarding the precursor that the team will be using for printing purposes, and the CNTs alignment involved in the process. As a result, there are major challenges, especially with the CNTs alignment, because relevant testing must be performed before having a final design for the alignment structure.

The team's sponsor desires a maximum concentration of CNTs in each droplet extruded onto the printing platform, and determining whether or not this is achieved with nanoscale objects can only be done by checking the material extruded using imaging microscopy, and observing how many CNTs are present. Aditionally, extruding a consistent amount in every droplet may or may not be possible by simply using an extruding nozzle/needle with a controlled force implemented. Experimentation with this system is underway.

Then there is the disassociation between alignment and pyrolysis. Alignment of the CNTs can be achieved by the presence of an electromagnetic field at an optimum temperature of 100 K with minimum damage and destruction, while pyrolysis of the composite through convection has required a temperature of at least 373 K to occur effectively. In order to combat this, LED and UV curing has been implemented due to the short wavelength energy it introduces without any significant increase in temperature.

A number of other possible concerns have arisen throughout the research process. The ratio of CNTs to the ceramic polymer composite is large enough to alter the color of the material to a dark opaque; therefore presenting the possibility of uneven convection of the material as it is being cured with LEDs. However, testing for this issue did not bring forward any observable inconsistencies.

B. Extrusion

Concerns involving the risks and reliability of the final product revolve around the material and functioning of the printer. From the initial process of extruding the polymer, it must be ascertained that the polymer composite's viscosity is compatible with the method of extrusion – if it is too thick for the chosen extrusion nozzles or needles, they could become clogged and consistency will be lost, destroying the quality of the printed product. Testing of these components will be done in order to better understand the flow properties of the composite through each, allowing the optimum method to be chosen so as to prevent clogging.

C. Personnel Safety

Safety of the user has been a paramount factor in the decisions matrices for each component considered for this project. A great example is the laser method for curing - though it was a strong contender for the curing method, the laser presented numerous risks on its own and failed to make sense when compared to other, safer, methods.

Heating of the system will be inevitable with the constant translation of components, the conduction of an electromagnetic field, and multiple LEDs shining throughout the interior. An insulated case will cover the entire system to ensure that any nearby personnel will not be in danger while the printer is in operation. Sensors for temperature and UV radiation, as well as an internal camera observing the printer platform, will be included to keep personnel aware of what's going on at all times.

The potential of a gas being emitted during the curing process is a possibility, and in order to counteract it, a ventilation system will be used to direct this gas away from the users and out of the lab. After careful research and discussion with the graduate students who have worked with the material previously, it has been determined that the only serious threat of this gas is the smell attributed to it – the chemical composition is not harmful when proper ventilation tactics are used.

In case of an emergency, an emergency shut-off button will be placed at an obtainable position. And any and all information concerning the system, such as its components, instructions on proper operation, and safety measures and precautions, will all be compiled clearly in an included user manual.

IV. Procurement

A. Purchase Orders

Since the material to be printed is a novel material with relatively different properties compared to those of the already existing printing materials, some of the printer components must be modified to make a proper extrusion of the printing material. In order to do this, several components should be tested before purchasing them. However, because it has become difficult to find useful testing components, the team decided to start purchasing certain components that will be first tested, and then used if they work as expected. This procedure was done with the approval of the whole team as well as with the approval of the team's main sponsor. Table 4 shows the components that the team has already purchased with its corresponding prices. Additionally, a fourth purchase order request was sent to the Mechanical Engineering department on November 19th, requesting the 3D printer model that the team and the sponsor agreed to buy. Nevertheless, recently the ME department let the team know that the vendor is not accepting the order; as a result this order has not been placed yet. This situation might cause a delay in the project development, because the team will not be able to begin any printer modifications without this fundamental component.

Table 4 Purchase Orders Received

Component	Price
LED lights	$58.06
Inkshield	$66.00
Arduino Mega 2560	$45.95

B. Machining

Print stage and extrusion head may need to be machined, but these components will be consisting of very simple parts mostly ready from the orders, or easily obtainable from scraps in the machine shop, or already an object such as the syringes. None of the items will need to be heavily machined as to affect the project timeline.

V. Communications

In order to gain insight and knowledge Team 19 have been consulting and meeting with our sponsor/advisor/mentor Dr. Xu weekly. Team 19 has been emailing to our other advisors and mentors as needed based on their field of expertise. Team 19 have been meeting with our instructors biweekly to try to convey as much information as possible with them in fifteen minute slots. Team 19 has been conveying our improved and updated ideas and models in our reports using our technical writing skills and in our PowerPoint updates using our presentation skills.

The team members mostly keep in touch via text messaging or e-mail. In addition the team has been meeting on a weekly basis. In these meetings, each team members are assigned a specific task to complete for the next team meeting. Also, any new research or ideas are discussed amongst the team to see if the ideas are beneficial to the project. These meetings help keep a steady flow of the team's progress, and it helps to see where the team is at in correlation to the Gantt chart.

VI. Environmental and Safety Issues and Ethics

One of the top priorities of the team is to design a product that is as safe, ethical, and environmentally friendly as possible. This is the number one article in the Fundamental Canons (from the Code of Ethics for Engineers) and is paramount in Team 19's decisions. Because the team is altering an existing 3D printer to fit the sponsor's needs, the control of the printer's ethical and environmental impacts should be taken into consideration.

Safety issues and their solutions, such as the high temperature of the system during operation, were gone through in depth in section V, "Risk and Reliability Assessment". The greatest concerns involve the high temperatures occurring during the printing process, the multiple moving components of the system when it is running, and the possible emissions of gases from the material during the process. Each of these concerns has been addressed accordingly and Team 19 is confident that the system has been designed with the absolute minimum risk factors.

As for environmental issues, the component decisions are actually quite commendable in regards to environmental impact. Light Emitting Diode (LED) lighting will be used as the curing method in order to solidify the polymer composite. Not only do LEDs draw minimal amounts of power to light, they also carry life spans that long outlast their predecessors. The method of curing will be done using LED lighting in order to prevent significant temperature increases.

Even the material that the entire project revolves around will have its impact. In this case the polymer composite matrix has the potential to replace the use of metals in a number of industrial applications due to its magnificent mechanical, thermal, and conductive properties. This material can be extracted and manufactured much more easily than metals in a manner that use less resources and produces less toxins to the environment.

VII. Future Plans for Prototype and others

Room for improvement is inevitable in any design. With this project Team 19 hopes to leave a strong foundation for future design teams to build off of and develop more advanced methods and components.

A. Printer Speed

From the point of extrusion to the end of the curing process, improvements on the final 3D printer can and will have to be made to cut down the time taken to print a final product. Accomplishing a faster production time can be done in a number of ways, including a higher input power for the stepper motors, the addition of a dual extrusion head, a faster method of forcing the material out of the extrusion nozzle, and so on. In this regard, more research and testing of the printer would have to be done once it is completed to determine the optimal areas to be modified.

B. Advanced Extrusion

By the end of the Spring 2015 semester, Team 19's goal to have a 3D printer that can extrude simple, self-stabilizing geometric shapes from the polymer precursor matrix provided by our sponsor while preserving the material properties. In the future it is hoped that an additional extrusion head will be added to the 3D printer to print out a structurally sound foundation for more complicated objects to be printed with ease. Essentially in the future the geometry could be enhanced by adding a second extruder head would output a polymer without CNTs or a plastic to support the object where it is unable to stand on its own. In this way more advanced products can be created safely and simply.

C. Accessories / Aesthetics

Along with the commodities and components desired by the sponsor, numerous other modifications are available and possible for adding on to the final 3D printer. These components are not necessities; instead, they provide the users a more customizable platform to add features as they desire them. This could include anything from a second LCD display, a video display of the printing process that can pulled up on any mobile device, various ports for uploading, self-automated material loading, and virtually anything else one can imagine. Even portability may become a desired feature in the future, and with the research and testing phases being completed by the beginning of the spring 2015, it will only be a matter of compacting and modifying the components for ease of transportation to make this possible.

VIII. Gantt Chart and Resources

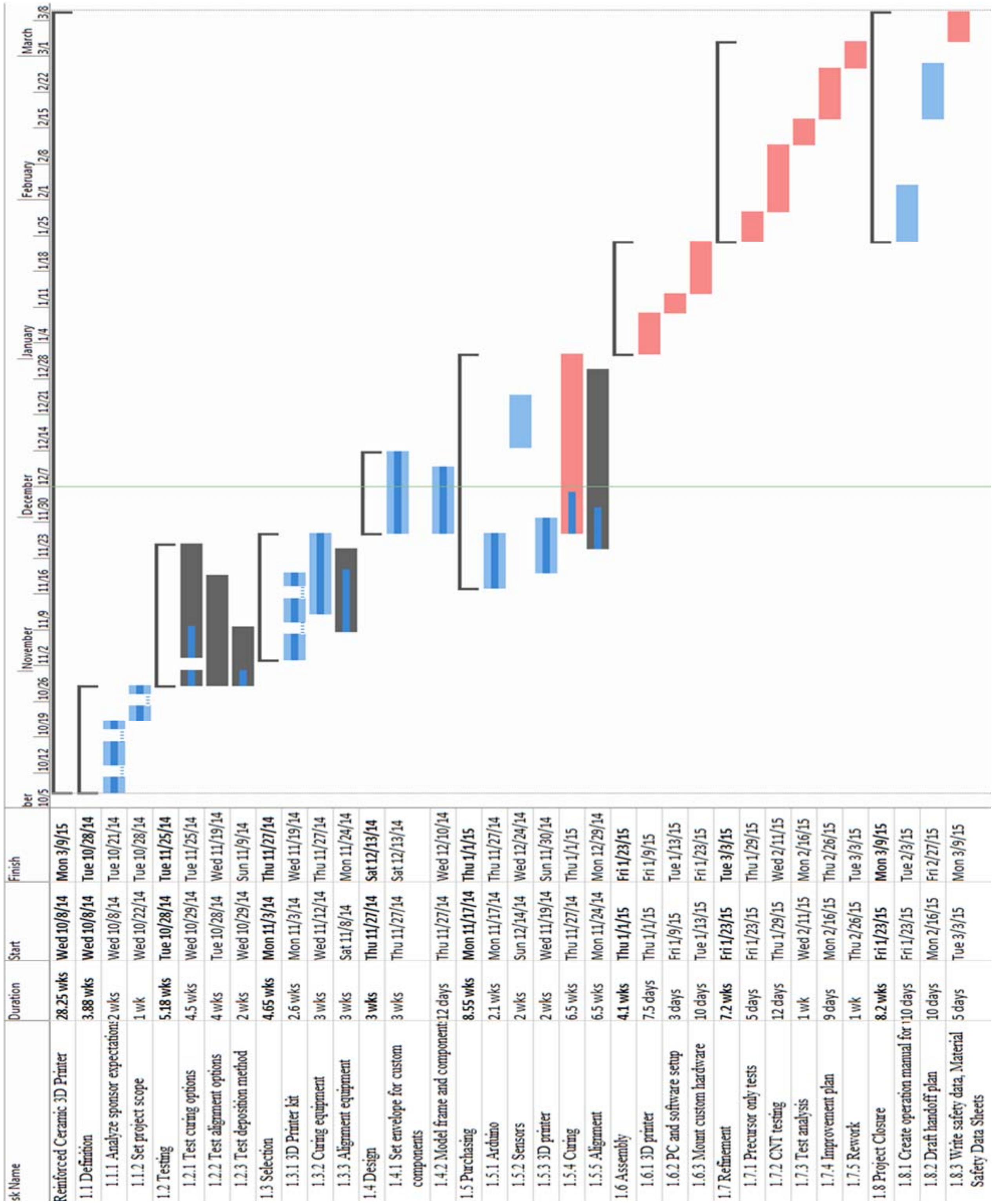

Figure 7: Gantt chart

IX. Budget

Since the beginning of this project it has been very difficult to create a reliable bill of materials, and thus a final budget. There are many components commercially available that will fit the requirements of this project; however, there is not enough experience with the type of printing material the team is working with. As a result, it has become challenging to find specific materials that will fit the sponsor needs and expectations, and additionally fit the printing material needs. Consequently, in order to be able to control expenditures a preliminary budget was created; however it is subjected to change. Table 5 shows the preliminary budget created. The cost column represent the price that the team will most likely be spending; and the percentage column represent the percentage of the total expenses that will be allocated to each component. It is subjected to change, because some behaviors of the printing material, or interactions between the 3D printer and other components cannot be predicted without seeing the outcomes with our own eyes. Although many research studies have been performed, there are still factors that will be determined once the team has the 3D printer set. It is important to mention that the budget only covers 56% of the $5,000 the team is allowed to spend.

Component	**Cost**	**Percentage of Total Costs**
3D Printer	$1,600.00	57%
Sensors	$220.00	8%
Camara	$200.00	7%
Housing	$180.00	6%
LCD Screen	$120.00	4%
Tools & Consumables	$80.00	3%
Power Supply	$85.00	3%
Curing	$80.00	3%
Inkshield Board	$66.00	2%
Field Generator	$60.00	2%
Microcontroller	$45.95	2%
Ventilation	$35.00	1%
Safety Equipment	$35.00	1%
Total	$2,806.95	100%

Table 5: Project budget

X. Conclusions

The majority of this semester has been consumed by research and experimentation with the polymer composite. By taking this time to better understanding the material properties and the optimal means of transforming the retrofitted 3D printer into the desired final product, Team 19 has been establishing a strong foundation for a final design for the project that will manufacture the desired material the polymer composite at its optimum capacities.

The team has carefully selected the major components for the project for this semester by using decision matrices and by consulting mentors and advisors. Most of this semester was spent on finalizing the goals and objectives decided by the members of the team, deciding on what calculations are needed and how these calculations will be helping the team with their design and the precise measures they will need to consider for modeling and manufacturing the components to be retrofitted This helped narrow down the scope even more and prepared the team for further and additional tasks to perform for the next semester. For the extrusion head component, the best method to extrude the precursor would be the syringe due to its ability to handle the fluid viscosity and the ease of cleaning. UV LED curing method was selected because of the size and its flexibility for placement around the print stage. The most important selection was the selection of an existing 3D printer. This was a meticulous process; members performed their own separate research based on multiple factors. These factors included open or closed hardware/software, clearance for a retrofitted extruder head, and the availability/shipping time. After each member selected his or her own choice, the team met with the sponsor for the final decision. A purchase order has been placed for the TAZ 4 and it will be arriving at the end of December.

For next semester, the 3D printer will be assembled and the design project will be moving rapidly. Testing with the syringe pump and UV LEDs will need to be recorded for time of curing as well as droplet sizes, and this will be done with the pure polymer. CNTs will then be added to the polymer and alignment of the CNTs will take place. Once this process is finished retrofitting the 3D printer can then be done. Furthermore, testing the ceramic with and without the CNTs will be important. By testing the material tensile strength, torsion strength, and hardness the team will be able to see how much of an effect the CNTs have on the physical and mechanical properties.

XI. References

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[8] Romyen, N., S. Thngyai and P. Praserthdam. "Alignment of Carbon NAnotubes in Polyimide under Electric and Magnetic Fields." *Journal of Applied Polymer Science* (2012): 3470-3475.

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[10] Xu, Chengying. *Multifunctional Ceramic Matrix Nanocomposites Manufacturing*. 14 October 2014. Document.

Appendix A Detailed Product Specifications

A. LED UV Lights

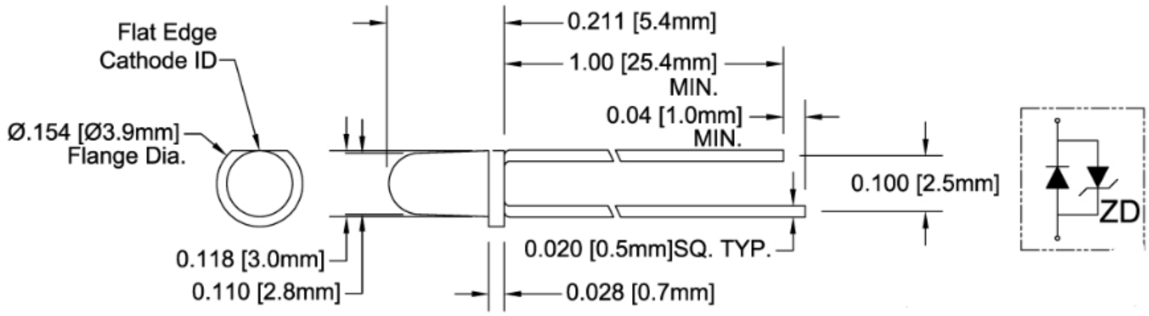

Figure 8: Drawing of LED

Table 6: LED specifications

Absolute Maximum Ratings

T_A = 25°C unless otherwise noted

Power Dissipation	120 mW
Forward Current (DC)	30 mA
Peak Forward Current [1]	100 mA
Electrostatic Discharge (Class1)	2000 V
Reverse Voltage	— V
Operating Temperature Range	-25 ~ +80°C
Storage Temperature Range	-30 ~ +80°C
Lead Soldering Temperature (3 mm from the base of the epoxy bulb) [2]	260°C

Notes: 1. 10% Duty Cycle, Pulse Width ≤ 0.1 msec. 2. Solder time less than 5 seconds at temperature extreme.

Electrical Characteristics

T_A = 25°C & I_F = 20 mA unless otherwise noted

Part Number	Forward Voltage (V)[1]			Recommend Forward Current (mA)			Reverse Current (mA)	Peak Wavelength λp (nm)[2]			Emitting Power (mW)		50% Power Angle (deg)
	MIN	TYP	MAX	MIN	TYP	MAX	MAX	MIN	TYP	MAX	MIN	TYP[3]	TYP
UV3TZ-390-15	3.0	3.4	3.8	10	15	20	100	387.5	390.0	392.5	5	10	15
UV3TZ-395-15								392.5	395.0	397.5			
UV3TZ-400-15								397.5	400.0	402.5			
UV3TZ-405-15								402.5	405.0	407.5			
UV3TZ-390-30	3.0	3.4	3.8	10	15	20	100	387.5	390.0	392.5	5	10	30
UV3TZ-395-30								392.5	395.0	397.5			
UV3TZ-400-30								397.5	400.0	402.5			
UV3TZ-405-30								402.5	405.0	407.5			

B. Taz 4

1. Specifications
   - Print Surface: Heated Borosilicate glass bed covered with PET film
   - Print Area: 298mm x 275mm x 250mm (11.7in x 10.8in x 9.8in)
   - Print Volume: 20,500cm^3 (1238 in^3) of usable space
   - Top Print Speed: 200mm/sec (7.9in/sec)
   - Print Tolerance: 0.1mm in X and Y axes. Z axis is dependent on layer thickness
   - Layer Thickness: 0.075mm to 0.35mm (0.003in - 0.0138in)
   - Supported Materials: ABS, PLA, HIPS, PVA, and wood filaments
   - Usable Filament Sizes: standard 3mm (0.1in)
   - Overall Dimensions: 680mm x 520mm x 515mm (26.8in x 20.5in x 20.3in)
   - Weight: 11kg (24.25lbs)
   - Power Requirements: 100 - 240 VAC
   - Temperature: Maximum operating temperature (Extruder), 240C (464F)
   - Temperature: Maximum operating temperature (Heated Bed), 120C (248F)

2. Includes
   - 24V power supply
   - Quick Setup Guide
   - Complete documentation
   - Filament Feed tube
   - Toolkit bag
   - 15 Piece Metric Hex Key Set
   - Pliers, Needle Nose
   - Tweezers
   - Standard Precision Knife
   - Dental Pick
   - Flathead Bristle Brush
   - Part Removal Knife (clam knife)
   - Metric Ruler
   - Acetone-safe Bottle (acetone not included)
   - Budaschnozzle with 0.35mm Nozzle
   - One year warranty and support

Appendix B FEM, modeling and other structural and analytical work

```
clc
clear all
% Thermal Analysis for LED

%LED specs
P_d = 0.120; %W
%max temperature operating range
T_m = 80; %Celsius
%ambient temperature
T_a = 23; %Celsius
%Forward Voltage
V_f = 3.4; %V
%radius of LED
r = 0.003; %m
%height of LED
h = 0.0054; %m
%wavelength of LED
lambda = 405; %wavelength
%viewing angle for LED
theta = 30; %degrees
%peak forward current
I_p = 0.100; %A

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

%heat generation for LED
% Volume of cylinder
V_c = pi*(r^2)*h;
%V_c = 1.5268 * 10^-7 m^3
%Volume of a sphere
V_s = (4/3)*pi*(r^3)*0.5;
%V_s = 5.655 * 10^-8 m^3
%heat generation
q_g = (P_d*0.7)/(V_s + V_c)
% 0.7 is an assumption of heat percentage from LED compared to light
% heat generated = 401.5 kW/m^3

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

%heat transfer - conduction
%material of LED plate- Aluminum- k=205W/mK
k = 205;
%Area of a cylinder
A_c = (2*pi*r*h)+(2*pi*(r^2));
% A_c = 0.1583 m^2
%Area of a sphere
A_s = 2*pi*(r^2);
%A_s= 0.05655 m^2
q_cond= -k*(A_s+A_c)*(T_a-T_m)
%q_cond= 2.511 W*m
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

%heat transfer- convection
%heat transfer coefficient ranges from 2-15 W/m^2*K
%assumption take average of h_c
h_c = 7; % W/m^2*K
q_conv= h_c*(A_c+A_s)*(T_m-T_a)
%0.0857 W

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%

%heat transfer- radiation
%emissivity of aluminum ranges from 0.04(polished)-0.25(oxidized)
e = 0.1;
%sigma-Stephan-Boltzman constant W/m^2*T^4
sigma = 5.67*10^-8;
q_rad = e*sigma*(A_s+A_c)*((T_m^4)- (T_a^4))
%1.24*10^-4 W


%Electric Field Calculations

%permittivity of free space, in units of (Farads/meter)
e_0 = 8.854.*(10^-12);

%relative dielectric constant of the liquid resin, dimensionless
e_1 =  4.9;

%length of the inclusion, in units of (meters)
L = 3*10^-6;

%radius of the inclusion, in units of (meters)
R = 0.5*10^-9;

%radius of the inclusion, in units of (meters)
a = ((R^2/2)+(L^2/12))^(1/2);
%a = 2;

%applied electric field, in units of (volts/meter)
E = 0:2:490000;

%Boltzmann's Constant, in units of (JK^-1)
k_B = 1.38*(10^-23);

%absolute temperature, in units of (K)
T = 300;

%beta
B = 1;


%parameter defining the relative strengths of the dipolar interaction and thermal agitation
%dimensionless, if chi > 1 then the CNT will algin
chi = (pi.*e_0.*e_1.*(a^3).*((B.*E).^2))./(k_B.*T)
```

```
plot(E, chi)
xlabel('Applied Field Strength (Volts)')
axis([0 18000 0 8])
ylabel('Orientation Parameter')
grid on
```

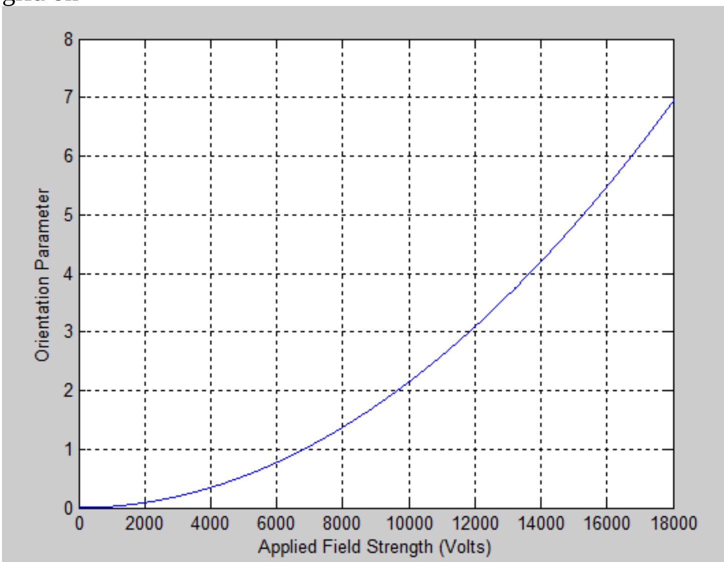

Figure 9: Field strength vs. orientation parameter

Appendix C Preliminary Designs

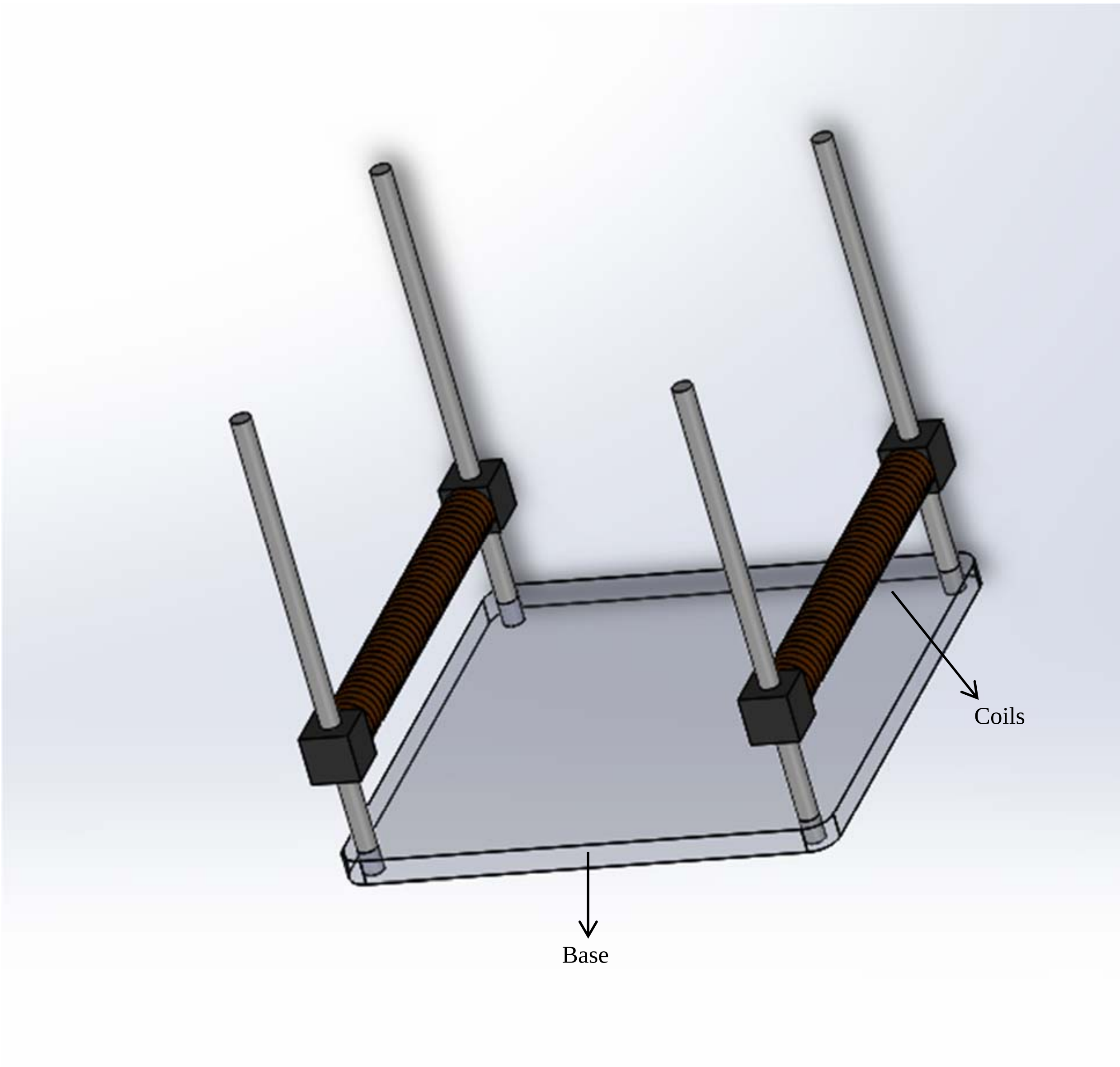

Figure 10: CAD model of potential alignment field setup

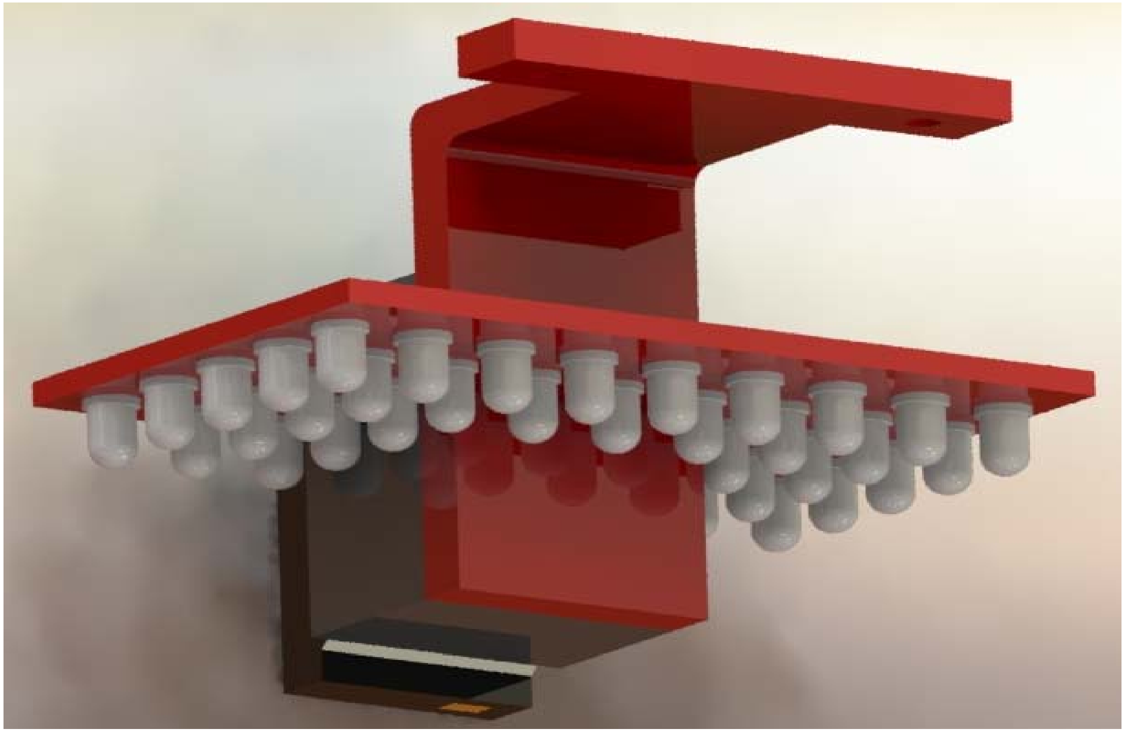

Figure 11: CAD model of LED array on extruder head

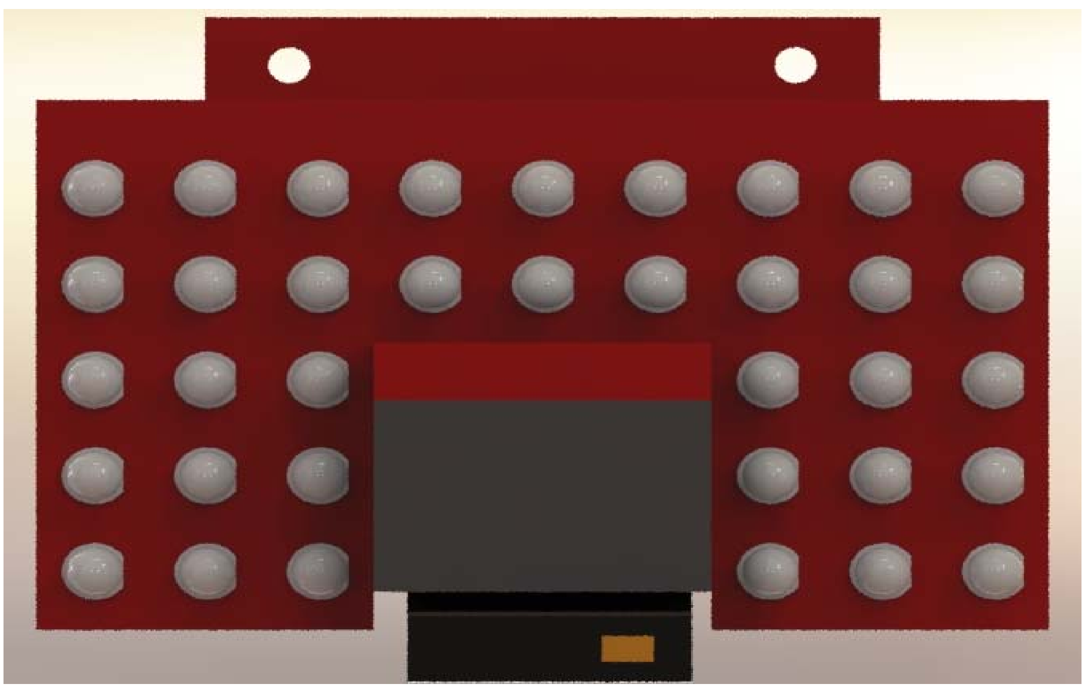

Figure 2: CAD model of LED array (top view)