Background

Team 19's sponsor, Dr. Cheryl Xu, has challenged us to deliver a 3D printer capable of layering ceramic composites reinforced with carbon nanotubes (CNTs) aligned in a way to best take advantage of their properties. By themselves, the mechanical properties of ceramics make them non-ideal for many applications, but ceramics reinforced with CNTs improve many of these properties such as strength, electrical and thermal conductivity, and temperature stability. It is the opinion of the team that this project's goals represent a novel application of 3D printing technology. This opinion is reinforced by a review on the available literature, meetings with sponsors, and consultation with experts in CNT applications and 3D printing.

Print Material

The material that the printer will use to create solid parts is a liquid polymer precursor that is similar to water in viscosity. After being cured via heat or UV irradiation, the precursor solidifies into a translucent material with similar properties to epoxies and other thermosetting resins. After the material is cured, it can be subjected to pyrolysis whereby the polymer structure is converted to a ceramic material composed mainly of silicon carbide (SiC). It is to this precursor that the CNTs will be added, in order to achieve the performance desired by the customer.

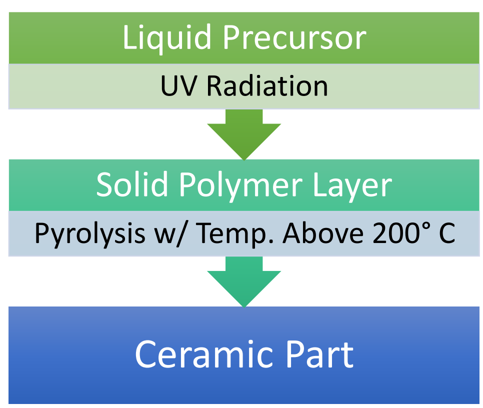


Figure 1 State Transformation of Print Material

Extrusion System

Because the uncured print material is a low-viscosity liquid at room temperature, the team has selected a syringe pump type system in order to accurately extrude the appropriate amount of slurry.

The syringe pump will be controlled by either an Arduino microcontroller, or directly from the RAMBO controller board on the TAZ 4 3D printer. Using a design from PIULabs in Milan, the team can mount a syringe pump directly onto the printer rails. This design is optimized to use a maximum of 3D printed parts in addition to a standard stepper motor.

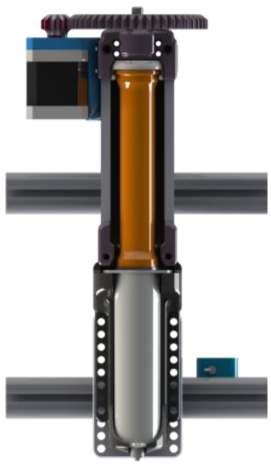


Figure 2 Syringe Pump Designed to be Mounted on a 3D Printer

Material Curing

The three curing processes that the team has been investigating include the hot plate, laser technology, and UV light. The hot plate was discarded immediately due to its lack of uniform heat dispersion. The laser was also discarded because of safety reasons. Currently, the team is developing an array to insert LED ultraviolet lights and test this as a curing method. This array will be attached to the extrusion head base allowing the material to be cured after it is being dropped on the printing platform.

3D Printer

The parameters that the team used to decide what 3D printer model would be purchased include ease of modification, software compatibility, clearance around the print head, and price. Additional consideration was given to printers with open source hardware and software components and also those that were preferred by the sponsor. The team ultimately selected the Lulzbot TAZ 4 printer The printer selected will be customized in order to implement the curing process, the CNT alignment unit, and a proper extrusion mechanism that will be able to print the novel material mixture.

Alignment System

After the material slurry is deposited onto the print stage, the Carbon Nanotubes will be dispersed throughout each extruded droplet. Inside the droplet the CNTs will have arbitrary orientation, and in order to maximize the desired properties the team will have to induce alignment of the CNTs before the polymer is cured.

The team's research indicates that the CNT alignment can be accomplished by exposing the slurry to an electromagnetic (EM) field generated by a custom built device. An EM field can be induced by applying a high voltage, alternating current to two electrodes that are positioned astride the print material. Research is ongoing to determine the magnitude of the required magnetic field, and the amount of exposure necessary to achieve a minimum level of alignment.

Ancillary Sensors

The software used to control the 3D printer provides information on the position of the print head, the temperature of the hot head and print stage, and the percentage of the print remaining. The sponsor has requested additional sensing capability that will require the team to purchase and mount subsystems that can operate independently from the printer.

Budget

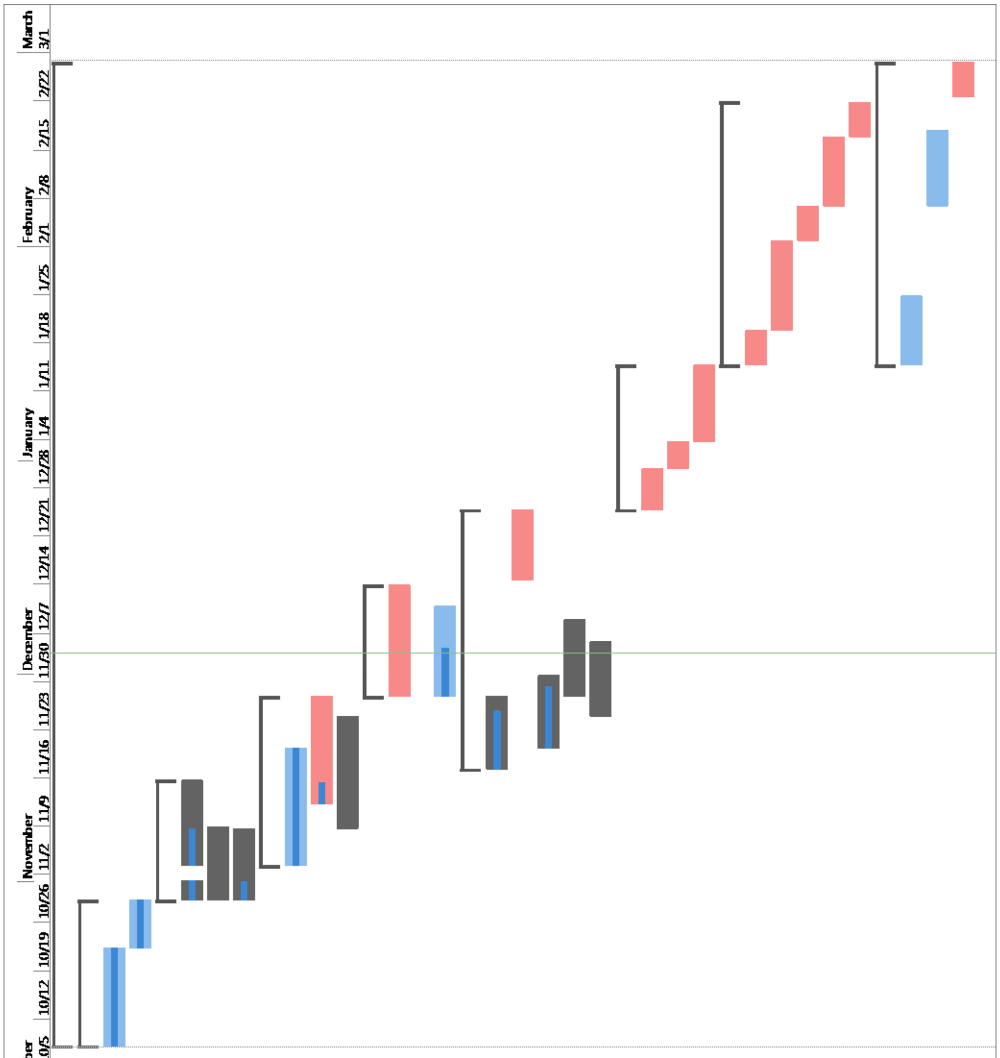
The team has been allocated $5000 to purchase all materials required to build the printer. Table 1 lists the major expenses of the project. Current cost estimates show that the team has 35% of the budget unallocated, leaving room for cost overruns and room for later feature expansion.

Table 1Project Expenditures

Team 19 Project Budget

Item	Cost	Percent of Total Costs
3D Printer	$ 1,995.00	61%
Housing	$ 400.00	12%
UV Curing Assembly	$ 125.00	4%
Camera	$ 125.00	4%
Power Supply	$ 120.00	4%
Field Generator	$ 95.00	3%
Sensors	$ 90.00	3%
Incidentals	$ 80.00	2%
Inkshield Board	$ 63.00	2%
Fans	$ 60.00	2%
Safety/PPE Equipment	$ 60.00	2%
Arduino Mega	$ 49.95	2%
Total	**$ 3,262.95**	**65%**

Gantt Chart



ID	Task Name	Duration	Start
1	**1 Reinforced Ceramic 3D Printer**	**26.45 wks**	**Wed 10/8/14**
2	**1.1 Definition**	**3.88 wks**	**Wed 10/8/14**
3	1.1.1 Analyze sponsor expectation:	2 wks	Wed 10/8/14
4	1.1.2 Set project scope	1 wk	Wed 10/22/14
5	**1.2 Testing**	**3.28 wks**	**Tue 10/28/14**
6	1.2.1 Test curing options	3 wks	Wed 10/29/14
7	1.2.2 Test alignment options	2 wks	Tue 10/28/14
8	1.2.3 Test deposition method	2 wks	Wed 10/29/14
9	**1.3 Selection**	**4.65 wks**	**Mon 11/3/14**
10	1.3.1 3D Printer kit	2.6 wks	Mon 11/3/14
11	1.3.2 Curing equipment	3 wks	Wed 11/12/14
12	1.3.3 Alignment equipment	3 wks	Sat 11/8/14
13	**1.4 Design**	**3 wks**	**Thu 11/27/14**
14	1.4.1 Set envelope for custom components	3 wks	Thu 11/27/14
15	1.4.2 Model frame and component:	12 days	Thu 11/27/14
16	**1.5 Purchasing**	**7.05 wks**	**Mon 11/17/14**
17	1.5.1 Arduino	2.1 wks	Mon 11/17/14
18	1.5.2 Sensors	2 wks	Sun 12/14/14
19	1.5.3 3D printer	2 wks	Wed 11/19/14
20	1.5.4 Curing	2 wks	Thu 11/27/14
21	1.5.5 Alignment	2 wks	Mon 11/24/14
22	**1.6 Assembly**	**3.8 wks**	**Wed 12/24/14**
23	1.6.1 3D printer	5 days	Wed 12/24/14
24	1.6.2 PC and software setup	4 days	Tue 12/30/14
25	1.6.3 Mount custom hardware	10 days	Sat 1/3/15
26	**1.7 Refinement**	**7.2 wks**	**Wed 1/14/15**
27	1.7.1 Precursor only tests	5 days	Wed 1/14/15
28	1.7.2 CNT testing	12 days	Mon 1/19/15
29	1.7.3 Test analysis	1 wk	Sun 2/1/15
30	1.7.4 Improvement plan	9 days	Fri 2/6/15
31	1.7.5 Rework	1 wk	Mon 2/16/15
32	**1.8 Project Closure**	**8.2 wks**	**Wed 1/14/15**
33	1.8.1 Create operation manual for	10 days	Wed 1/14/15
34	1.8.2 Draft handoff plan	2 wks	Fri 2/6/15
35	1.8.3 Write safety data, Material Safety Data Sheets	5 days	Sun 2/22/15