# Carbon Nanotube (CNT) Reinforced Ceramic 3D Printer

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## Motivation

By marrying the unique mechanical and conductive properties of carbon nanotubes and the resilience and hard wearing abilities of ceramics, a new material can be produced that can serve in a variety of new and traditional roles. The work done by Dr. Xu has developed a method for producing this material via a molding process; the molded part is then machined into the final geometry and then converted to a ceramic. By 3D printing the material waste involved in the subtractive milling process can be avoided, and structures that are impractical to produce by machining are able to be formed.

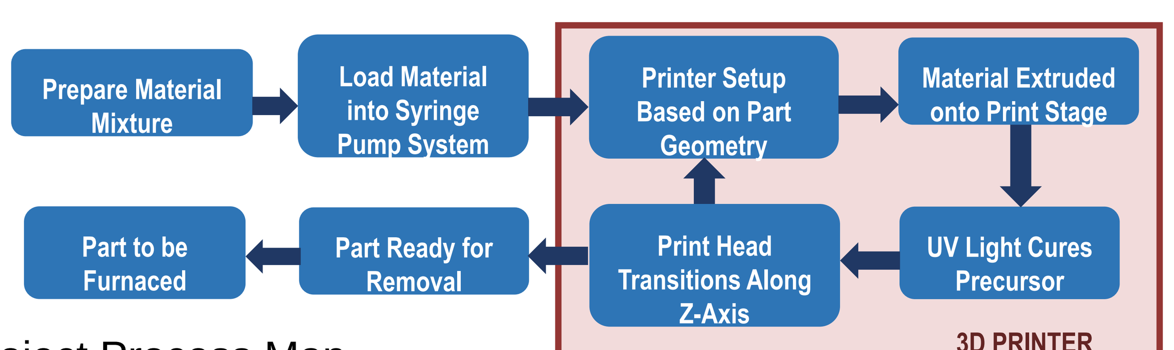
## Objective

***Modify a commercially available 3D printer to extrude a liquid material mixture containing a polymer based ceramic precursor and carbon nanotubes and then cure the material using UV radiation to form a solid having a predetermined size and structure that can be converted to a reinforced ceramic part.***

## Tasks

In order to accomplish the goals set out by the project sponsor, the team has fulfilled several design and engineering tasks including:

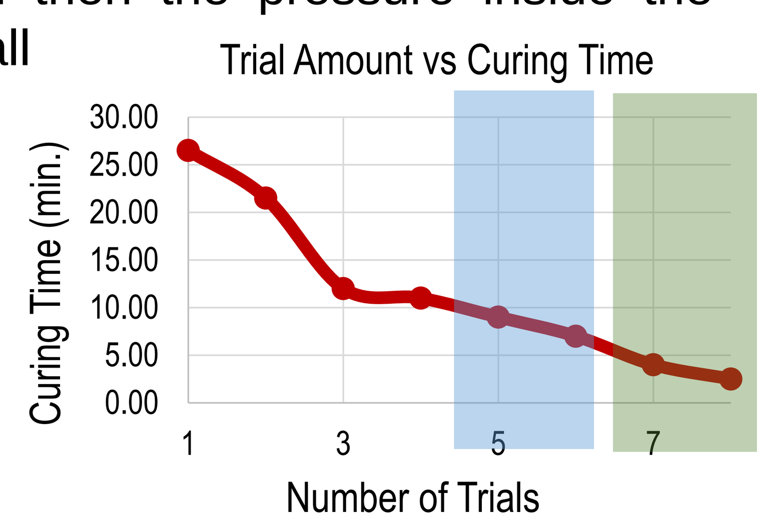
- Developed the material mixture composition for printing
- Designed experiments for optimization of print resolution
- Analyzed the results of experiments and purchased the requisite equipment
- Designed the custom hardware components for the extrusion and curing processes
- Fabricated above, and incorporated new hardware into existing printer systems
- Developed print settings and G-Code to efficiently produce printed parts




Project Process Map

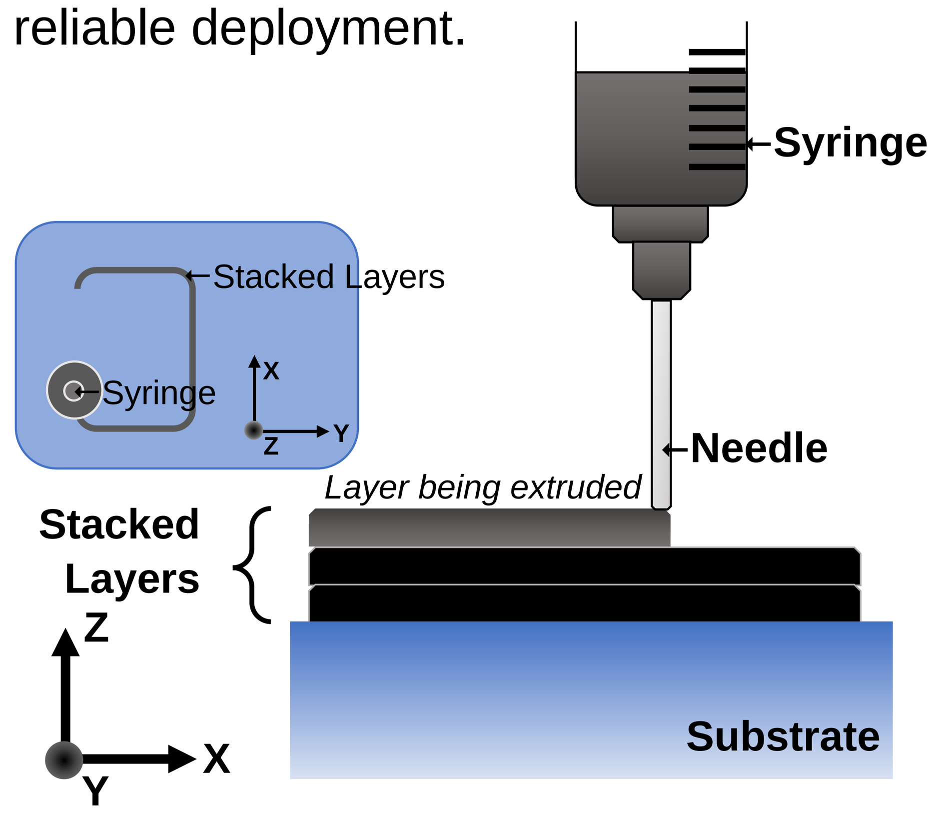
## Experimental Results

One goal of the experiments was to determine the optimal needle size. **A smaller needle size corresponds to a higher resolution.** However, if the needle is too small then the pressure inside the syringe prevents the extrusion. After all experiments the **400 micron needle** was selected. Another goal was to decrease the curing time by changing the test conditions. In the end UV bulbs were selected instead of the LED clusters and curing time was **2.5 minutes**.

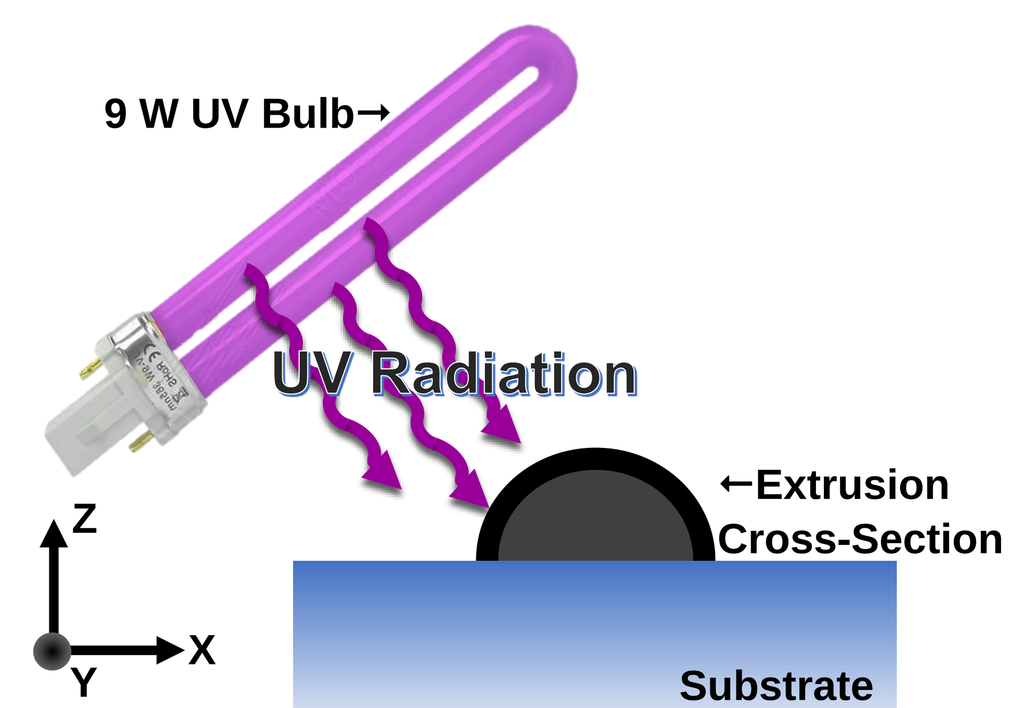



## Printer Design

The team required a robust 3D printer to serve as the basis of the project. The TAZ 4 from Lulzbot is an open source/libre printer that offers many opportunities to make modifications to its hardware and software. The ability to quickly switch from traditional FDM printing to the novel material mixture is critical to the overall quality of the final deliverable product. The group is using extrusion to force the material through a syringe needle to form coherent lines on the print stage. This process was determined to be less wasteful than other technologies and is finely suited for the viscous, semi-fluid nature of the print material. By using Ultraviolet light, the material can be cured to a solid polymer in a relatively safe and rapid process. The UV radiation is delivered through four 9W fluorescent bulbs which offer a low cost and reliable deployment.

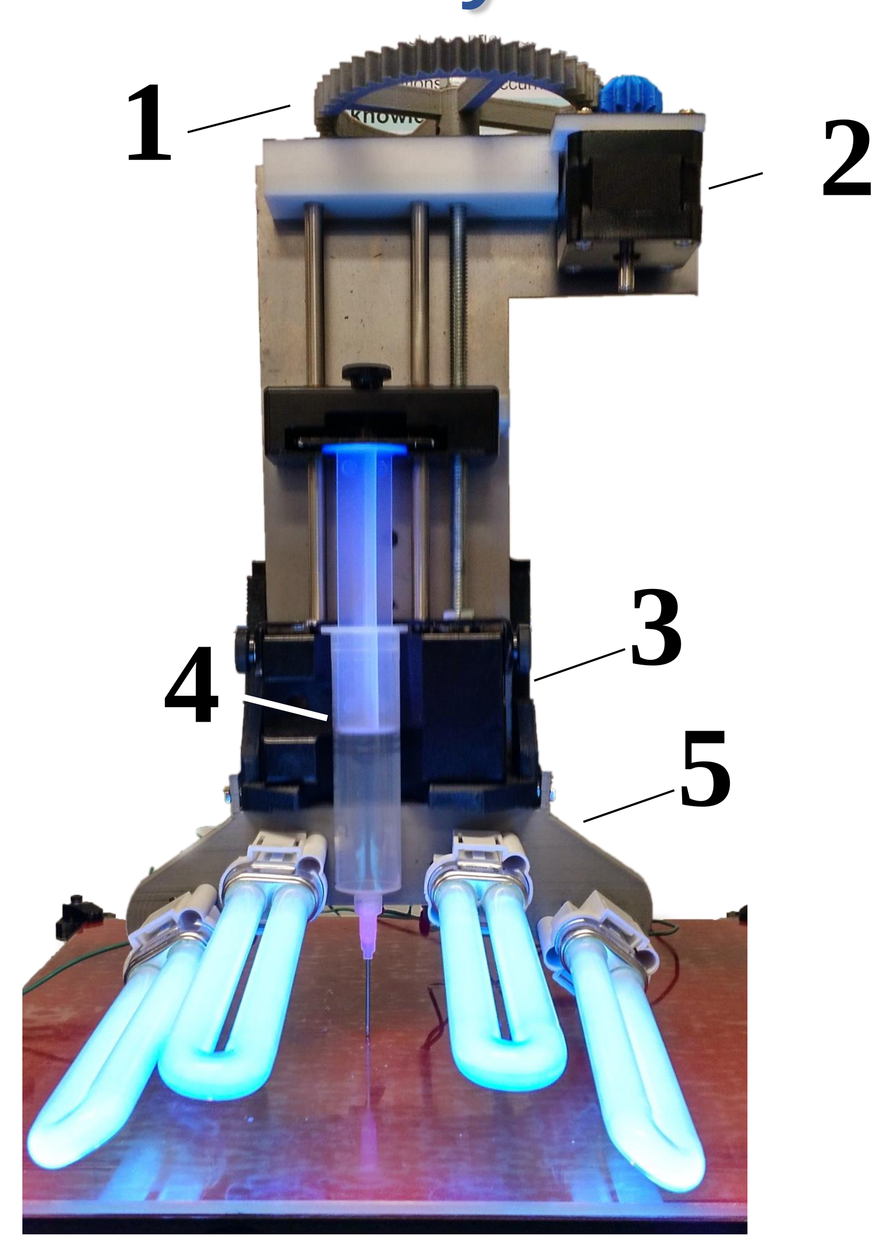



Layer by Layer Extrusion




UV Curing Methodology

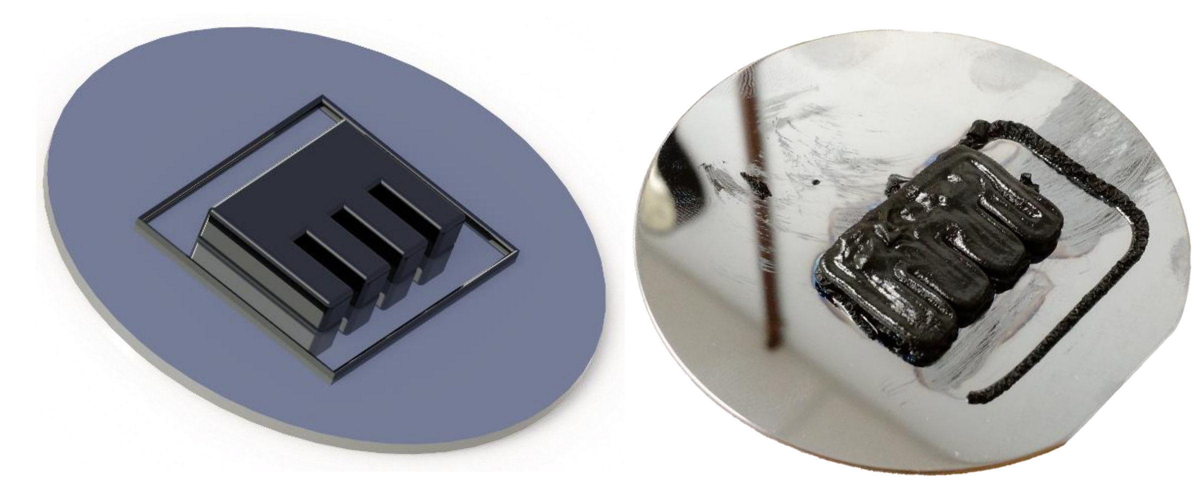
## Final Assembly




1. 3D printed ABS gear set
2. NEMA 17 stepper motor
3. Syringe holder
4. 20ml syringe and 600 micron diameter needle
5. 36W curing lamp array

## Analysis

The printer was able to print and partially cure objects that resemble the input 3D geometry, with reasonably good fidelity. Difficulty was encountered with mixing the material for printing, with inconsistent viscosity, material clumping, and poor dispersion of solutes leading to syringe blockages and the abortion of several print jobs. Printed parts were subjected to pyrolysis where they exhibited the expected amount of shrinkage due to burn-off of the reagent and polymeric components.
Print resolution may be enhanced if improved mixing techniques or dispersion methods allow for the use of smaller diameter needles in a consistent manner. Material mechanical and thermal properties were not tested as the sponsor was unable to provide control data or comparison samples.



Digital model of sample part (left) and printed part (right)

## Future work

- Replacement of the UV lamps by low profile, high wattage UV LED components would improve the density of curing energy and thus reducing curing times
- By adjusting the viscosity and composition of the print mixture, it is possible to reduce curing times and improve resolution by means of producing lines that have better self-cohesion and disperse less on the print stage.
- Fixture of an aluminum or copper heat sink and blower fan to reduce stepper motor heat buildup during heavy load
- Design and fabrication of an enclosure for the printer would allow for a means of environmental control, fume mitigation, and allow the mounting of additional UV sources while also reducing the exposure of operators to curing radiation.

1W UV LED (left) stepper motor heatsink (right)