

FDM 3D-Printed 17-4 PH Stainless Steel

ITS PROPERTIES, BEHAVIORS, AND POTENTIAL

Sterling Kleist | Dr. Doug Dunham & Dr. Anthony Wagner | Materials Science and Engineering Department



BACKGROUND

17-4 PH stainless steel, often used in but not limited to the aerospace, medical, chemical, and food industries is a martensitic stainless steel known for its strength, hardness, and corrosion resistance. It is also magnetic and reasonably machinable.

FILAMET™ COMPOSITION

Classic fused-deposition modeling (FDM) 3D printing, done layer-by-layer, is made possible through Virtual Foundry (a Wisconsin-based company) 17-4 stainless steel filament:

- Composition (by weight %)
 - Polylactic acid (PLA plastic) – 12-13%
 - 17-4 steel – 87-88%
 - Iron (Fe) - ≥ 75.0 - $\leq 90.0\%$
 - Chromium (Cr) - ≥ 10.0 - $\leq 25.0\%$
 - Nickel (Ni) - $\leq 5.0\%$
 - Copper (Cu) - $\leq 5.0\%$
 - Niobium (Nb) - $\leq 1.0\%$

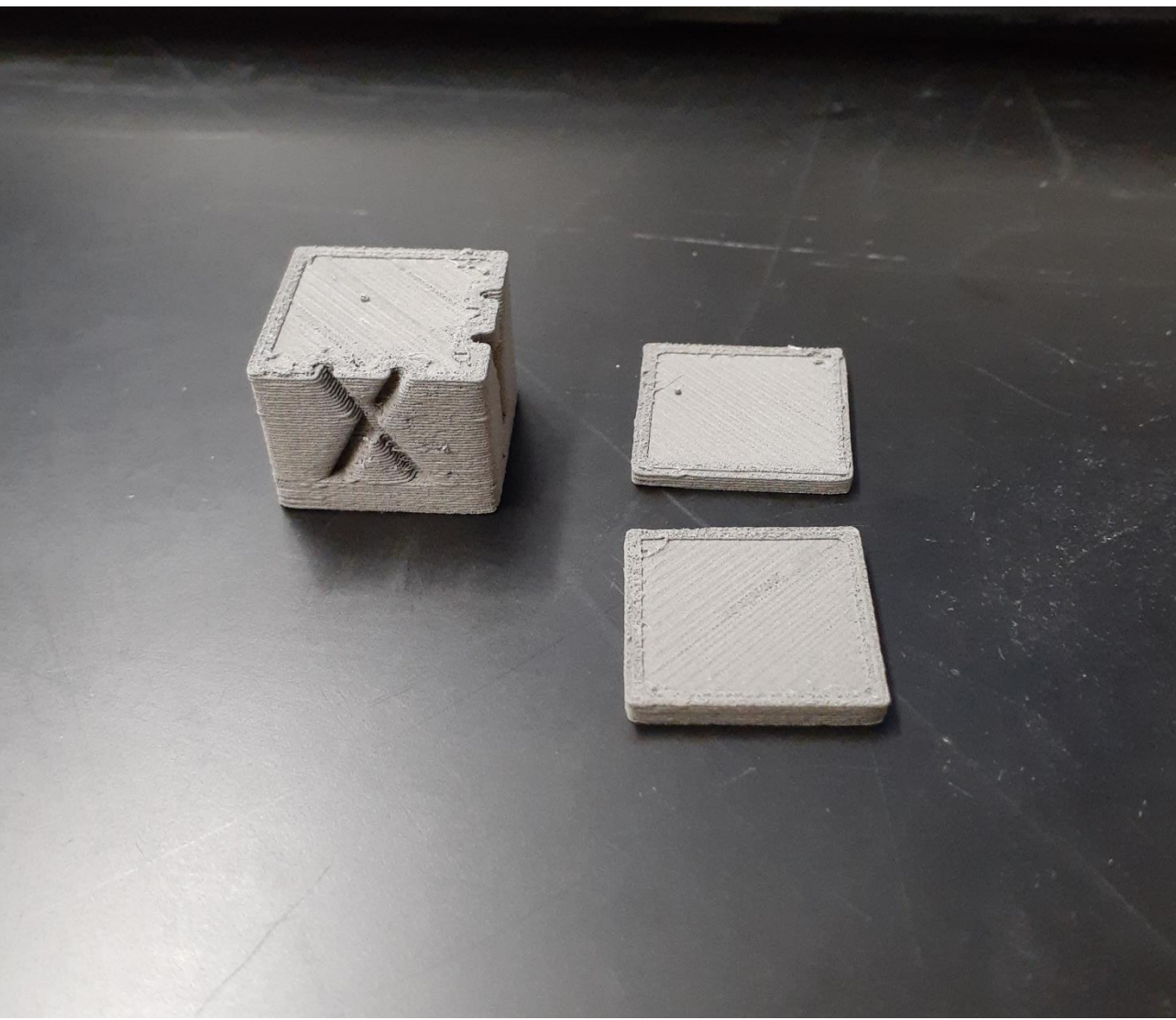
GOALS OF THE STUDY

This study aims to determine whether or not 3D printed 17-4 stainless steel can be made to closely resemble traditionally cast stainless steel in density and strength (compressive, tensile, and sheer). By achieving this, 3D printed steel could enable industry manufacturers to more-easily create part geometries previously inaccessible to them by means of FDM 3D printing.

METHODOLOGY

THE PRINTER

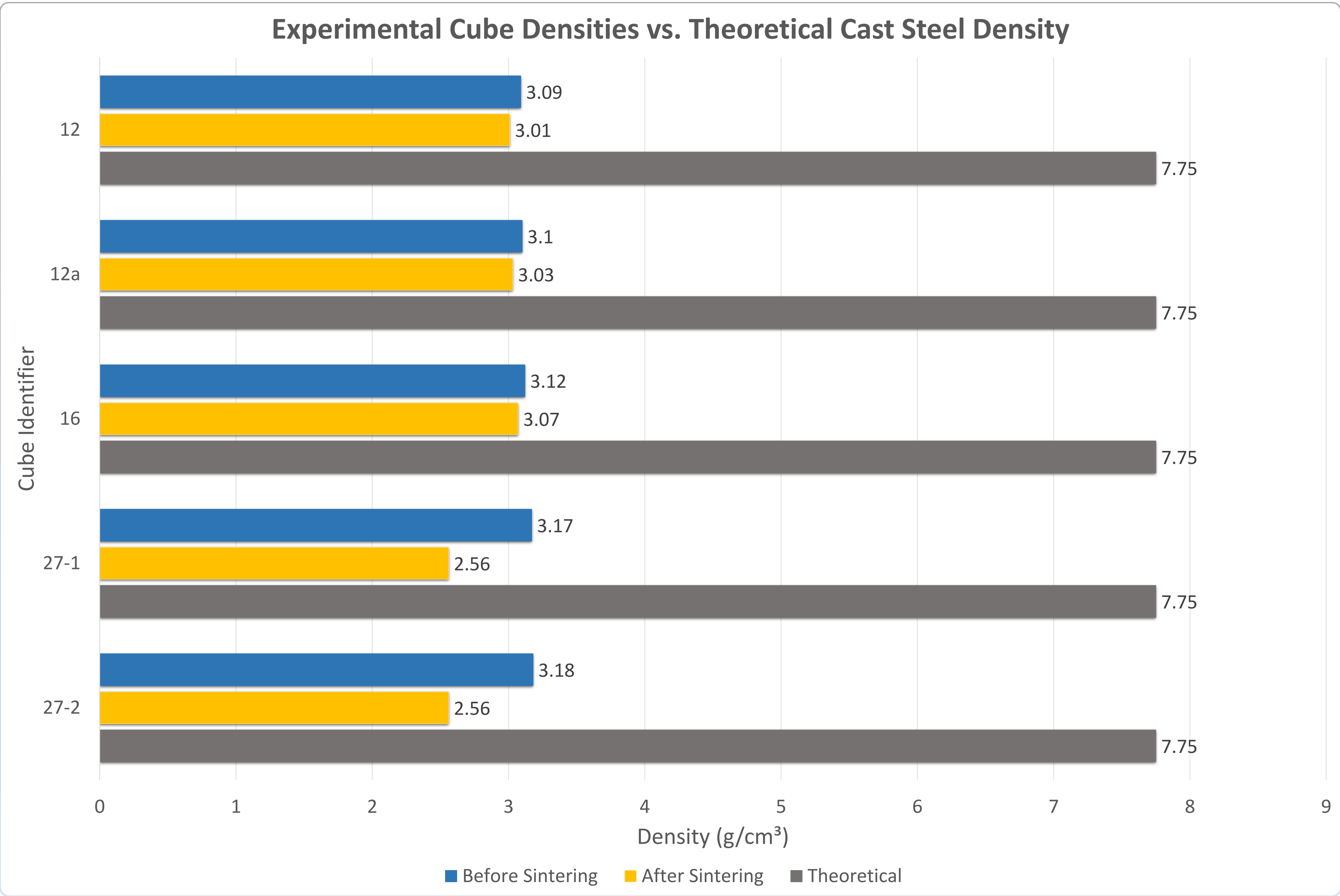
Due to the very brittle nature of 17-4 Filamet™, all printing has been done on a Prusa MK3S 3D printer. This model allows for an unobstructed vertical path between the unusually-large spool of Filamet™ and the print head, easing strain on the spool and filament.



Above is a partial print of the cube model, with 'X', 'Y', and 'Z' embossing to identify faces, printed in 17-4 Filamet™.



Above is a cutaway of one of the cubes from the first sintering run after the process was complete. Though there is a thin layer of sintered steel visible on the outside edge around the cube, it is clear the process isn't complete. Longer holds and more heat should contribute to more consistent densification, alongside object shrinkage.



RESULTS

PRINTABILITY

Overall, 26 revisions of a cube model were printed before the process became reliable. 22 of these revisions were attempted with a 0.6mm hardened steel nozzle. Within this set, 17 cubes were attempted and 9 succeeded. Some revisions attempted did not manage to make it past the first few layers before jamming and were not included in counting any significant attempts.

3 later revisions were attempted with a 0.8mm hardened steel nozzle. Within this set, 11 cubes were attempted and 11 succeeded. There is a positive relation between the overall flow rate of the filament during printing and the success of the print, though this relation is difficult to measure due to the many factors that affect flow.

DEBINDING AND SINTERING

Two post-processing runs have been conducted on the steel filament as of now, with both the 1200 and 1500°C furnaces.

The first run included the first successful iterations of the cube model: 12, 12a, and 16. These cubes had been printed using the 0.6mm hardened steel nozzle. During the run, a debinding temperature of 600°C was reached over 9.5 hours with a hold of an additional 2 hours. Once complete, the crucible was allowed to cool to room temperature before transferring to a smaller, more capable furnace. Here, the crucible was heated back to the previous 600°C with a controlled ramp up before ramping rapidly

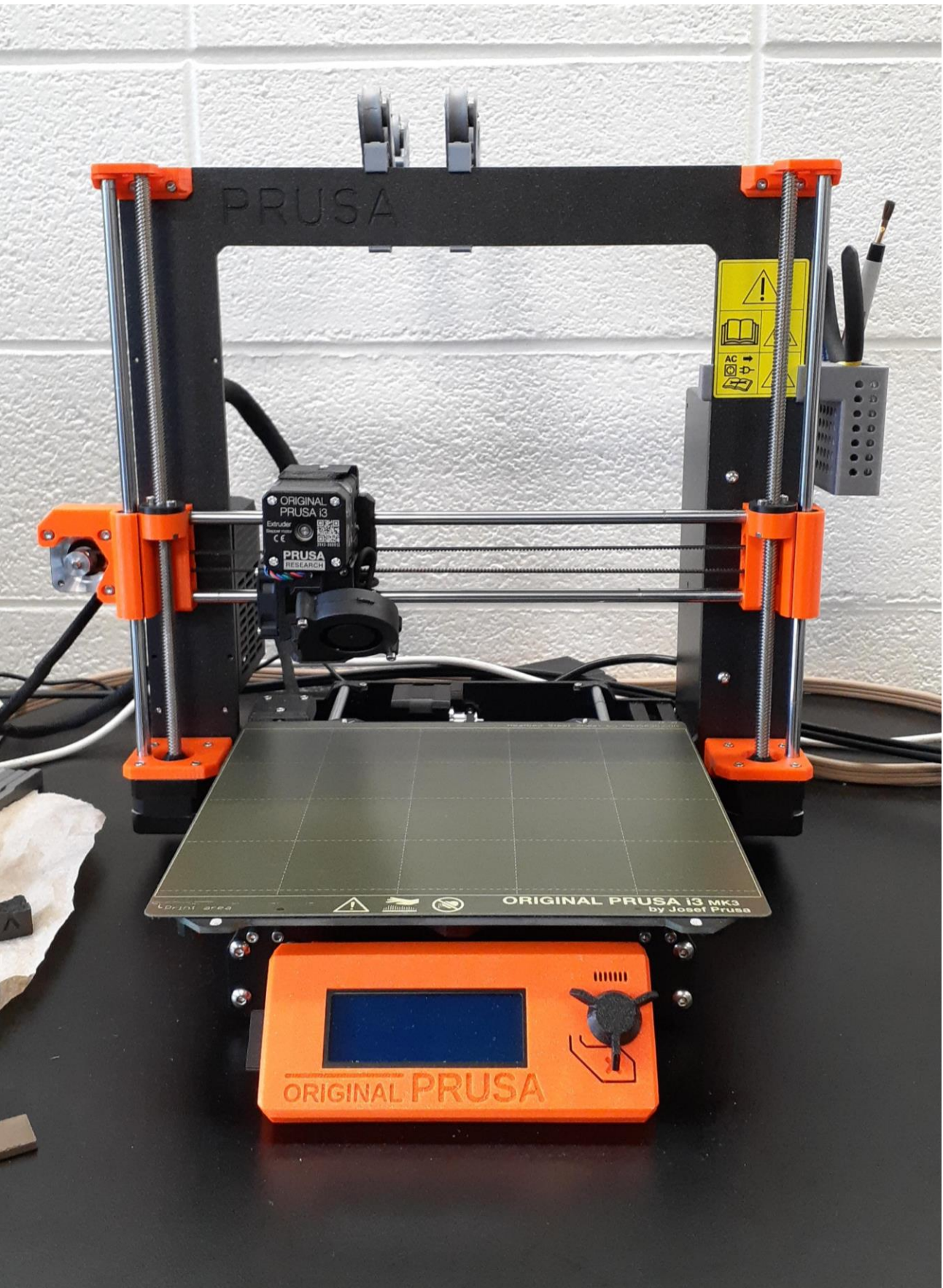
(5.25°C per minute) to 1232°C and holding for 5 hours. The goal – to achieve a near-theoretical density – was not reached in this timeframe, achieving an average density of 3.04 g/cm³.

The second run was like the first, though it was designed to accommodate only the 1200°C furnace (the same debind target was kept but the sintering target dropped). Due to machine limitations previously unknown, though the target sinter temperature of 1195°C was likely briefly reached, it was observed that the furnace only held at about 1100°C. The resulting average density of this run of cubes was only 2.56 g/cm³, as seen in cubes 27-1 and 27-2 above.

CONCLUSION AND DISCUSSION

Printing Virtual Foundry's 17-4 Stainless Steel Filamet™ is unique, though like PLA in most behaviors. With a 0.8mm nozzle, achieving the necessary flow to prevent jamming is easily attainable, compared to the more difficult 0.6mm nozzle.

Due to the unique composition of the filament, it can be difficult to reach the temperatures required to densify the material. This has caused significant delays, making it difficult to test hotter sintering targets. Though only two runs have been attempted so far, both my own data and relevant research done in similar processing from other parts of the world suggest that sintering hotter aids in controlled densification. More research will be conducted this summer.



The Prusa MK3S used for this research, modified with a spool carrier on top to accommodate the large rolls of Filamet™

THE FILAMENT

The Virtual Foundry Filamet™ is unique and vital to this project. It is composed of roughly 87% steel particles by weight, with the remaining 13% in PLA. PLA, being the most widely-used thermoplastic in FDM printing, binds the alloy particles together and allows the printer to reshape the "memory" of the filament without actually interacting with the metal particles at all.

Due to its high metal content, the filament conducts heat very quickly and I've found the greatest success in printing quickly with a 0.8mm nozzle, twice the standard diameter of nozzle for this model of printer.

POST-PROCESSING

After printing, the product exhibits few qualities resembling stainless steel. It is gray and fragile; it can be scratched or picked at with your finger. The next step in the process involves debinding and sintering. Debinding the product includes heating it in a crucible to 600°C to "burn out" the PLA binder. At this point, the product is incredibly brittle and can be destroyed by hitting it with a spoon. Sintering, the other half of the process, involves heating the product between 950°C and 1350°C, with my limited attempts so far reaching 1232°C and 1200°C in two separate attempts, in that order.