# Innovating the FDM Process - Metal Powder PLA Printing

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## Research Question

Metal 3D printing is generally a costly form of fabricating highly customizable parts. Common forms of metal additive fabrication is DMD, SLS, SLM, WFLB, and etc [1]. The research proposed here is that of low cost metal fabrication using powder infused filament that can be printed on a standard Fused Deposition Modeling (FDM) printer (printing process shown in Figure 1). By utilizing an electric furnace, the plastic can be removed during the sintering process and the powder will fused together into a single low-cost metal fabricated part. Traditionally, metal 3D printing techniques cost approximately $400,000 on average [2]. This low-cost fabrication method aims to provide manufacturing with a more affordable alternative.

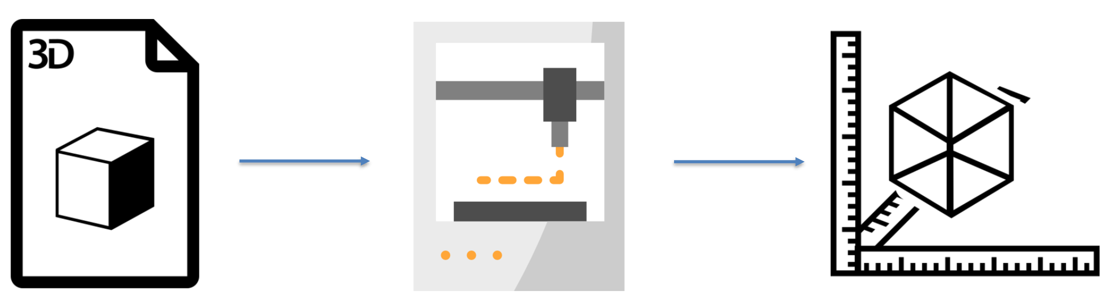


Figure 1. Diagram of Additive Manufacturing process from CAD -> Printer -> Product

## Metal AM Technologies

There is a wide range of metal AM techniques Figure 2 shows common solutions. Definitions of such methods are the following:

- SLM: Selective Laser Melting is using a laser scanner to precisely fuse metal powders together to form a part [3].
- SLS: Selective Laser Sintering is using precise high power laser beams to sintering metal parts [1].
- DMD: Direct Metal Deposition is a powder blow technique where metal powder is blown and simultaneously melted via laser to form a part [3].
- WAAM: Wire Arc Additive Manufacturing utilizes robot welding platforms to build metal parts layer-by-layer [1].

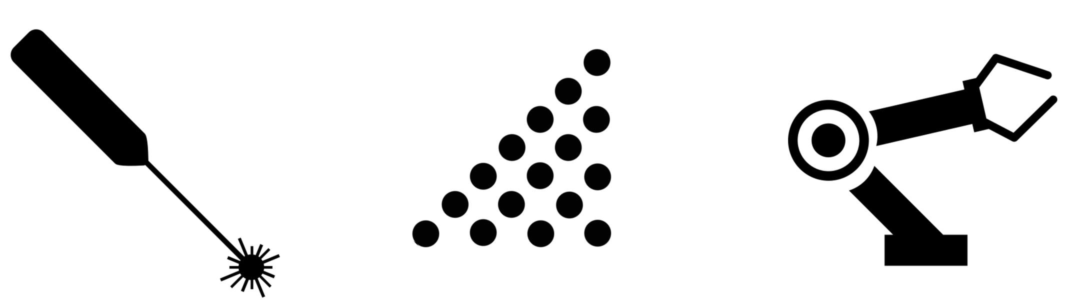

Figure 2. Laser powder and robotic wire fed systems are some of the most common metal AM techniques

## Procedure

- Figure 3 shows a summarized procedure. Figure 4. shows reference imaging throughout the process

Printing

- Metal Powder infused PLA

  Copper – 90% Metal : 10% PLA

  Bronze – 87% Metal : 13% PLA

  Stainless Steel – 80% Metal : 20% PLA

- The filament passes through a preheater to 60C and then fed into the extruder
- A part can be sliced and 3D printed with the same settings as low-cost PLA, the only difference is it needs to be slowed down to between 10-20mm/s

Sintering

- The refractory ballast is a Magic Black Powder (MBP) water mixture
- The parts are painted and suspended in the MBP mixture
- After the crucible is prepared with the parts, it is placed inside an electric furnace to sweep through the necessary temperatures in order to sinter the material.
- The MBP mixture coats the part in a protective black layer to maintain features; this layer needs to be sanded off
- The final part is a 100% metal part fabricated on a low cost FDM printer and there is an expected shrinkage of approximately 7%

Post Processing

- Before sintering, the parts are sanded to smooth the layer lines
- After sintering, the parts are grinded down to remove the soot/oxide layer shown in figure x
- Following grinding, the parts are buffed and polished to give the part a metallic appearance

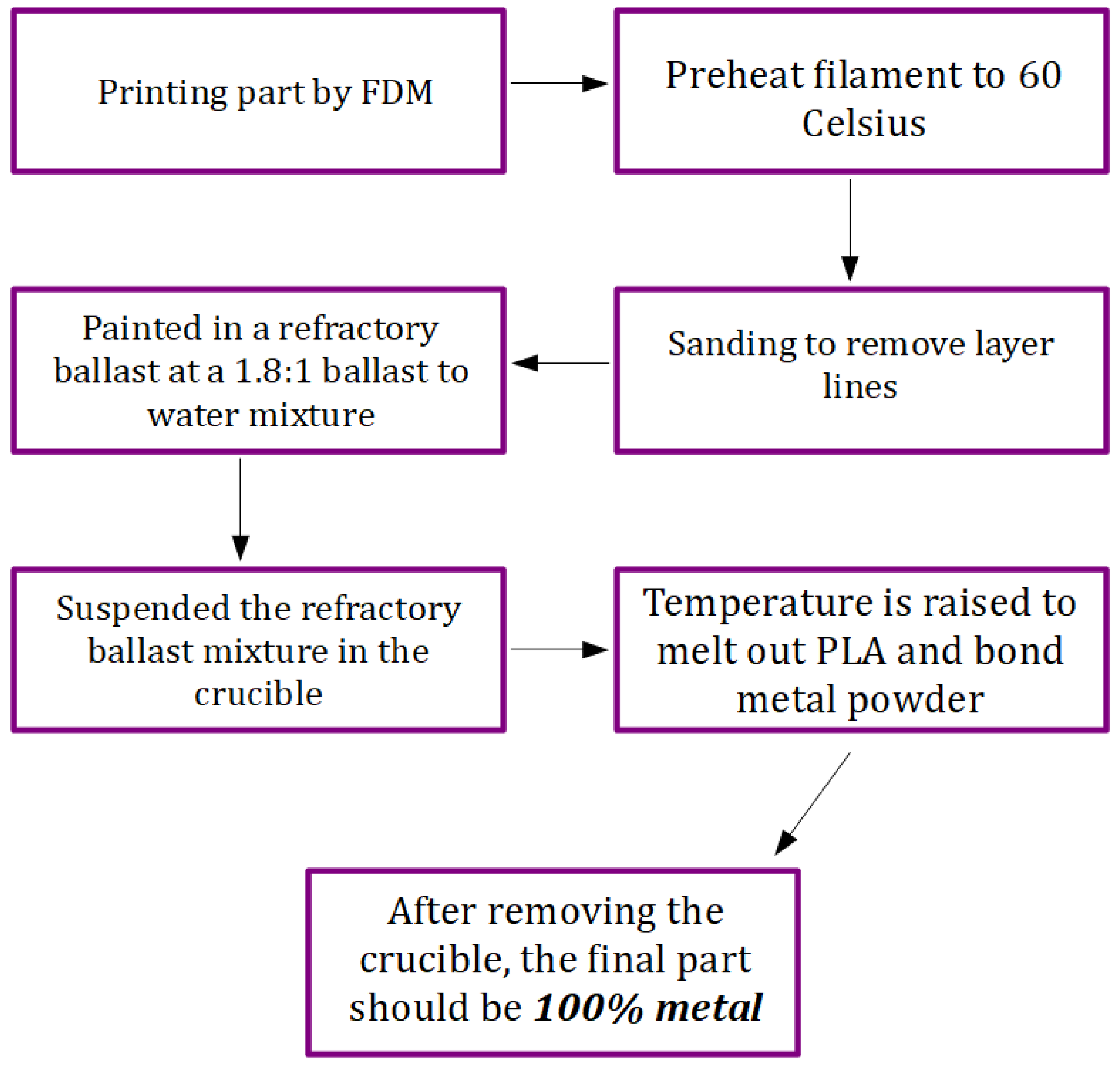


Figure 3. Flowchart of the fabrication process

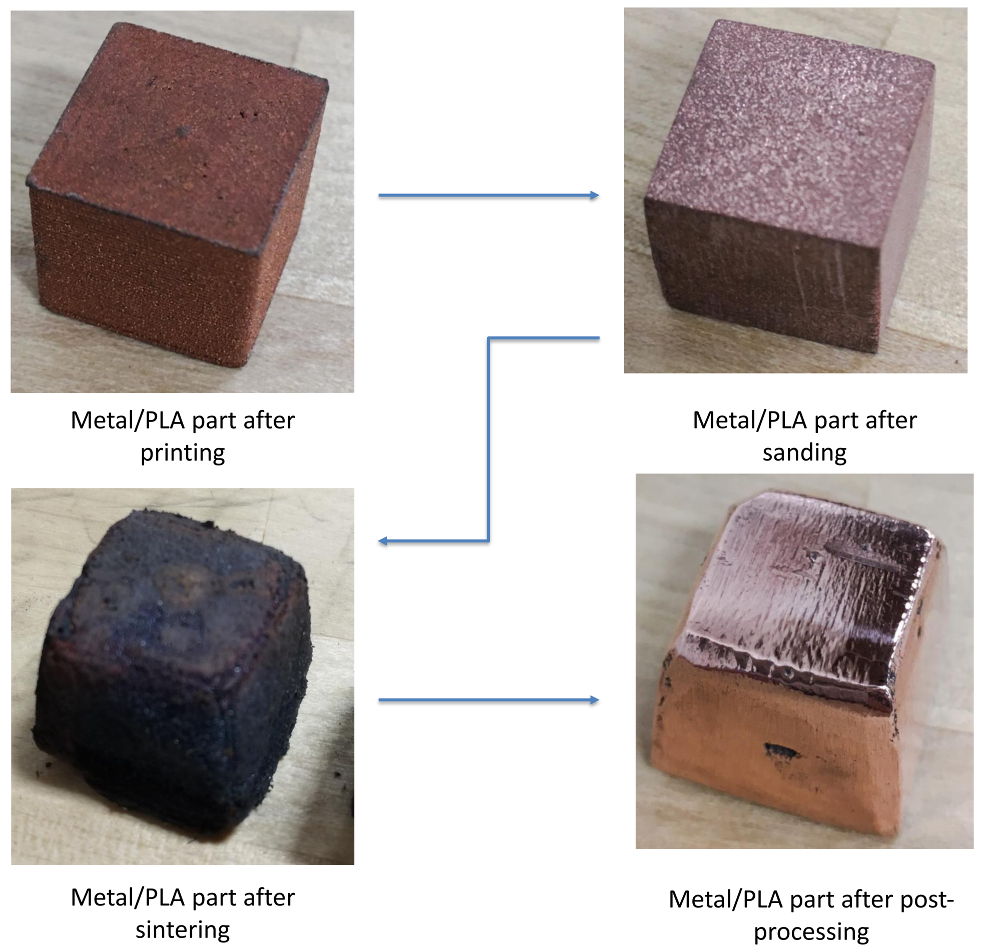


Figure 4. Images of specimens throughout the process

## Results

- The metal PLA composite material is fairly easy to print with
- Through various tests, the sintering process yields 100% copper metal parts
- Before sintering, the parts would not conduct electricity as the PLA would act as a dielectric
- After sintering, the parts can conduct electricity with approximately no PLA dielectric present as shown in Figure 5.

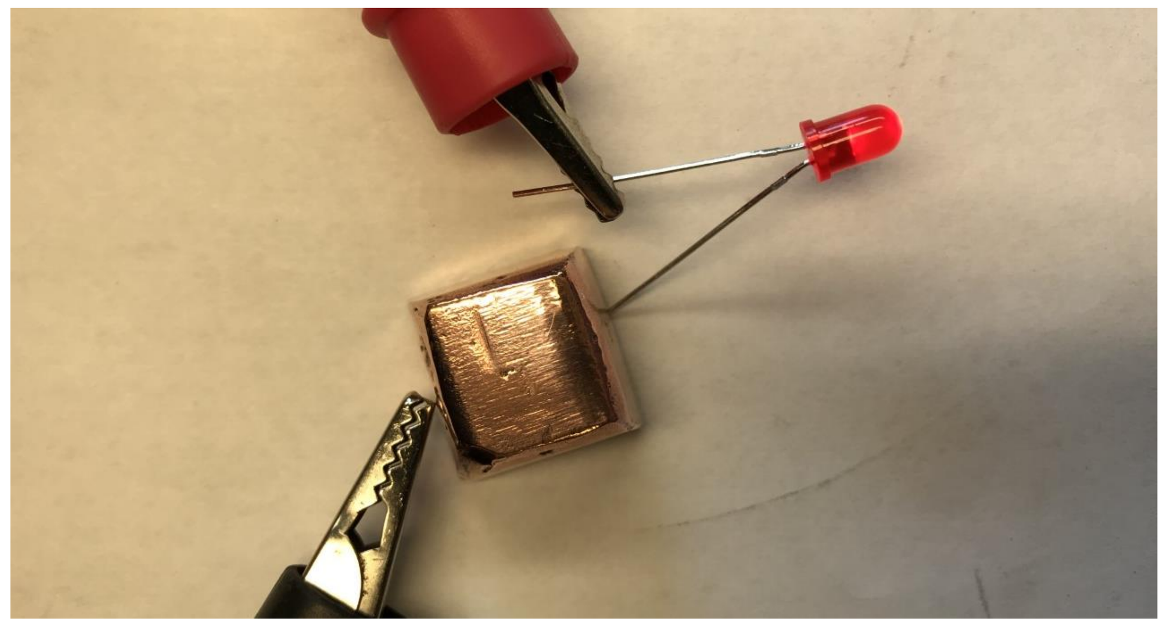

Figure 5. Polished material tested for conductivity

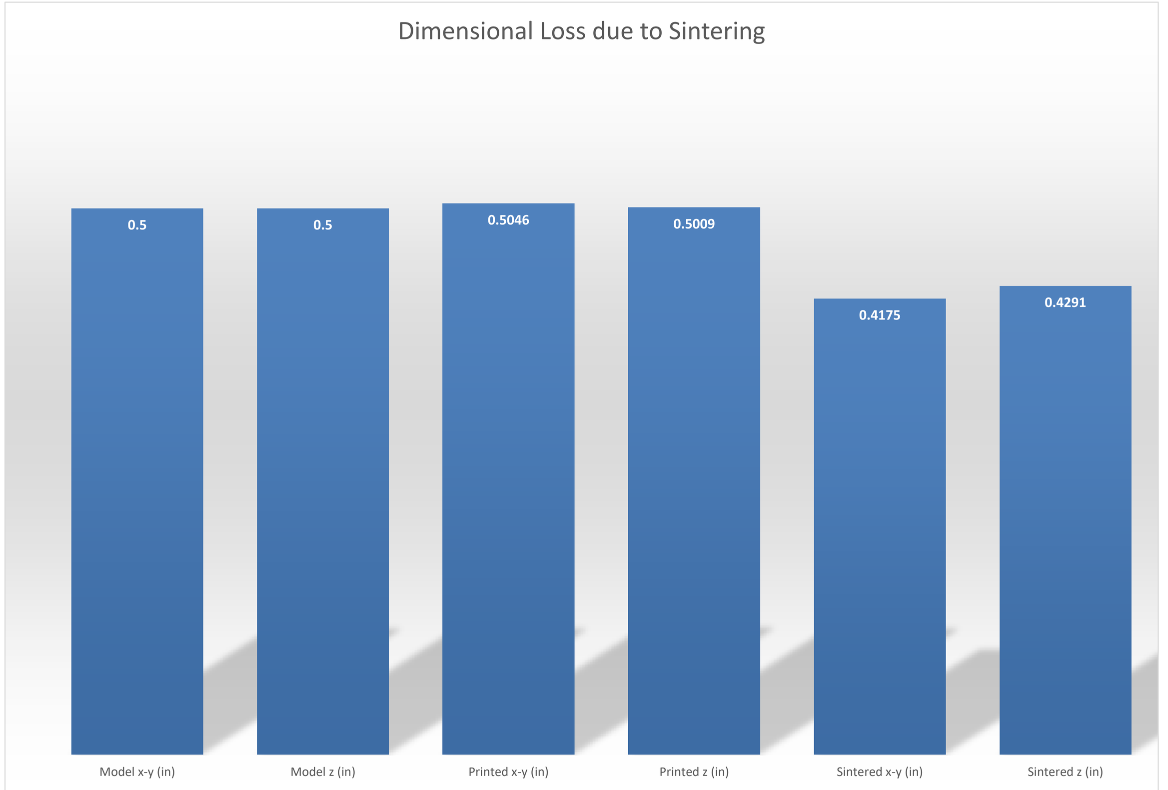


Figure 6. Shrinkage due to sintering

- As shown the shrinkage in the 0.5”x0.5’x0.5” test cubes was approximately 15%, this is likely due to the small size of the part and a larger part would perform better future work will validate this
- The sintering process is abrasive to the printed parts and the following printing settings are liable to result in failures as seen in Figure 7:

  Shells ≤ 2
  Infill < 80%

- For optimal strength, 100% rectilinear infill with at least 3 shells produces the greatest tensile strength [4],[5]

Figure 7. Metal/PLA part collapsed in on itself during sintering due to poor print settings

## Discussion

- The preliminary results show the feasibility of this metal 3D printing fabrication technique
- This fabrication technique can be performed for ***as little as $3,186***

  $2,000 Printer + $65 Prewarmer + $121 1Kg of Filament + $800 Furnace = $1,186

- This total cost is ***far less than the $400,000*** necessary for producing metal parts using current metal 3D printing technologies

## Conclusions

Thus far, this technique has been validated to produce metallic parts. The dimensional analysis shows a large amount of shrinkage in the z direction. This shrinkage could be mitigated in future tests with more evenly distributed cooling. Future work includes the following tests: mechanical by tensile, compression, modulus, and etc; microstructure analysis to visualize the material composition and porosity; energy consumption analysis for the entire fabrication; and cost analysis for the per unit mass cost to produce parts.

## References

[1] W. E. Frazier, “Metal additive manufacturing: A review,” J. Mater. Eng. Perform., vol. 23, no. 6, pp. 1917–1928, 2014.

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[3] A. Y. Kuan, D. Hoe-lian, P. Rebecca, and R. P. Web, “METAL 3D PRINTING VIA SELECTIVE LASER MELTING AND DIRECT METAL DEPOSITION: MATERIALS, PROPERTIES AND APPLICATIONS,” Prog. Addit. Manuf., 2016.

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