Additive Manufacturing and Characterization of Polylactic Acid (PLA) Composites Containing Metal Reinforcements

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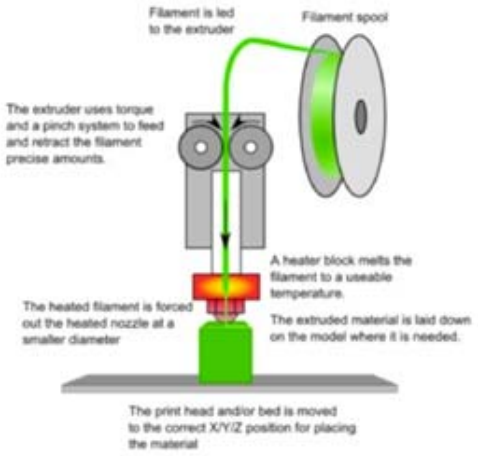
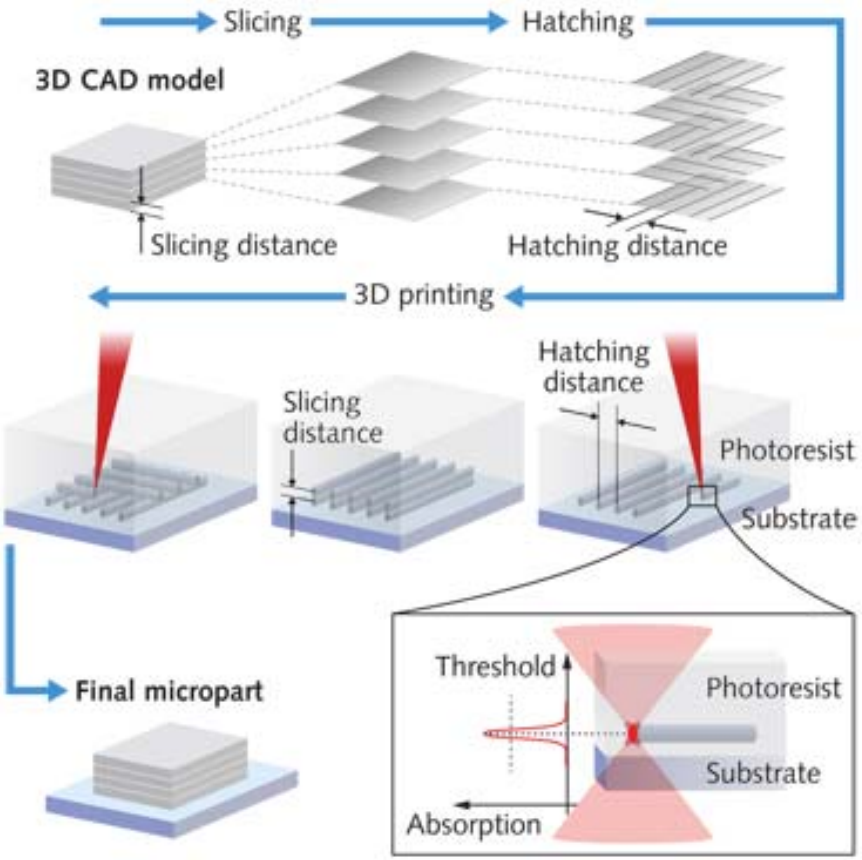
Additive Manufacturing

- **3D printing**
  - **3D CAD files are sliced**
  - **Filament is heated and extruded**



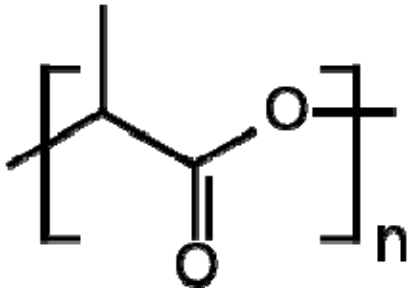


3D Printing Materials

- **Main 3D printer filaments**
  - **PLA**
  - **ABS**
- **Composite materials**
  - **Contain metal powders**
  - **Various fibers**

Polylactic Acid (PLA)

- **Benefits**
  - **Environmentally friendly**
  - **Does not release toxic fumes/safe for people**



- **Disadvantages**
  - **Does not last as long as other plastics.**
  - **Not as tough as ABS, based on fracture toughness testing**

Applications of Polylactic Acid

- **Films**
  - **Food packaging**
  - **Plastic bags**
- **Fibers**
  - **Upholstery**
  - **Disposable garments**
- **Biomedical applications**

Objectives

Determine the properties of the new PLA composite materials

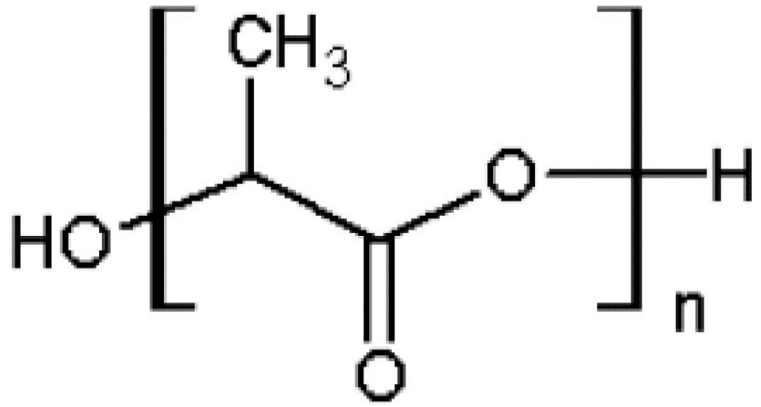
- Microscopy
- Tribology
- Tensile Strength
- Fracture Toughness
- Thermogravimetric analysis
- Differential Scanning Calorimetry

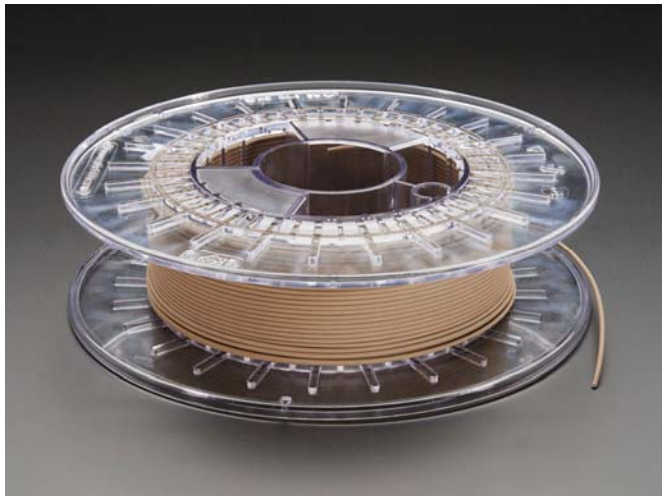
Compare the properties of the PLA with the PLA composites

- Are the PLA composites an improvement on the plain PLA materials?
- In what ways are these PLA composite materials an improvement?

Materials Used in Present Study

- PLA (Polylactic acid)
- Bronze fill PLA
- Copper fill PLA
- Magnetic Iron PLA
- Stainless Steel PLA

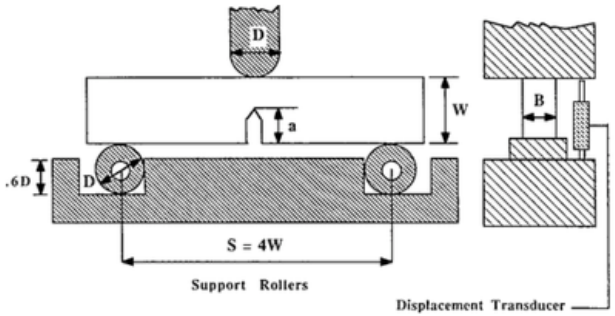




3-D Printed Materials

- **The test samples were printed at several different layer heights seen below:**
  - **Tensile bars - 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm**
  - **Wear test samples - 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm**
  - **Fracture toughness bars - 0.1 mm, 0.3 mm**
  - **Microscopy samples - 0.1 mm, 0.3 mm**

ASTM D638



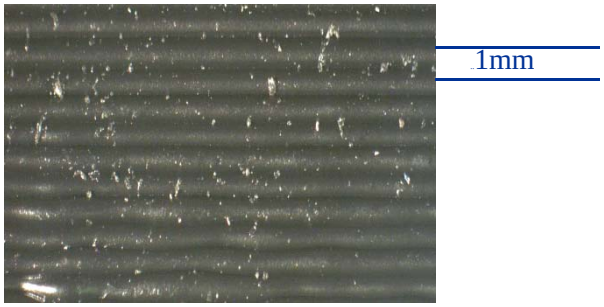
ASTM D5045

- **Three samples per condition**

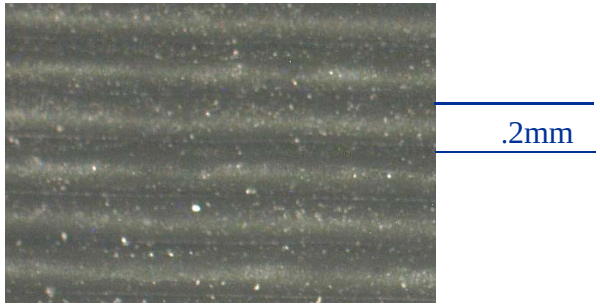
Macrostructure

- **Print resolution**
  - **Prints of different layer heights exhibit different structures. Different mechanical properties?**

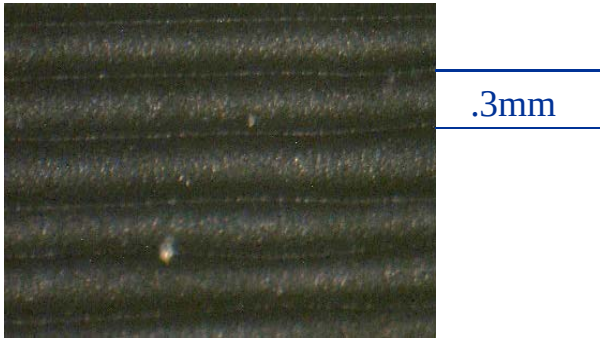
0.1mm



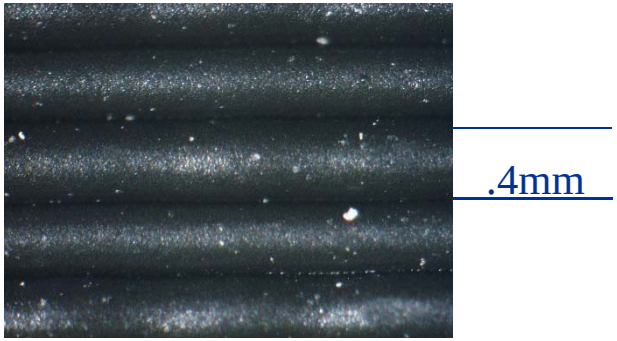
0.2mm



0.3mm

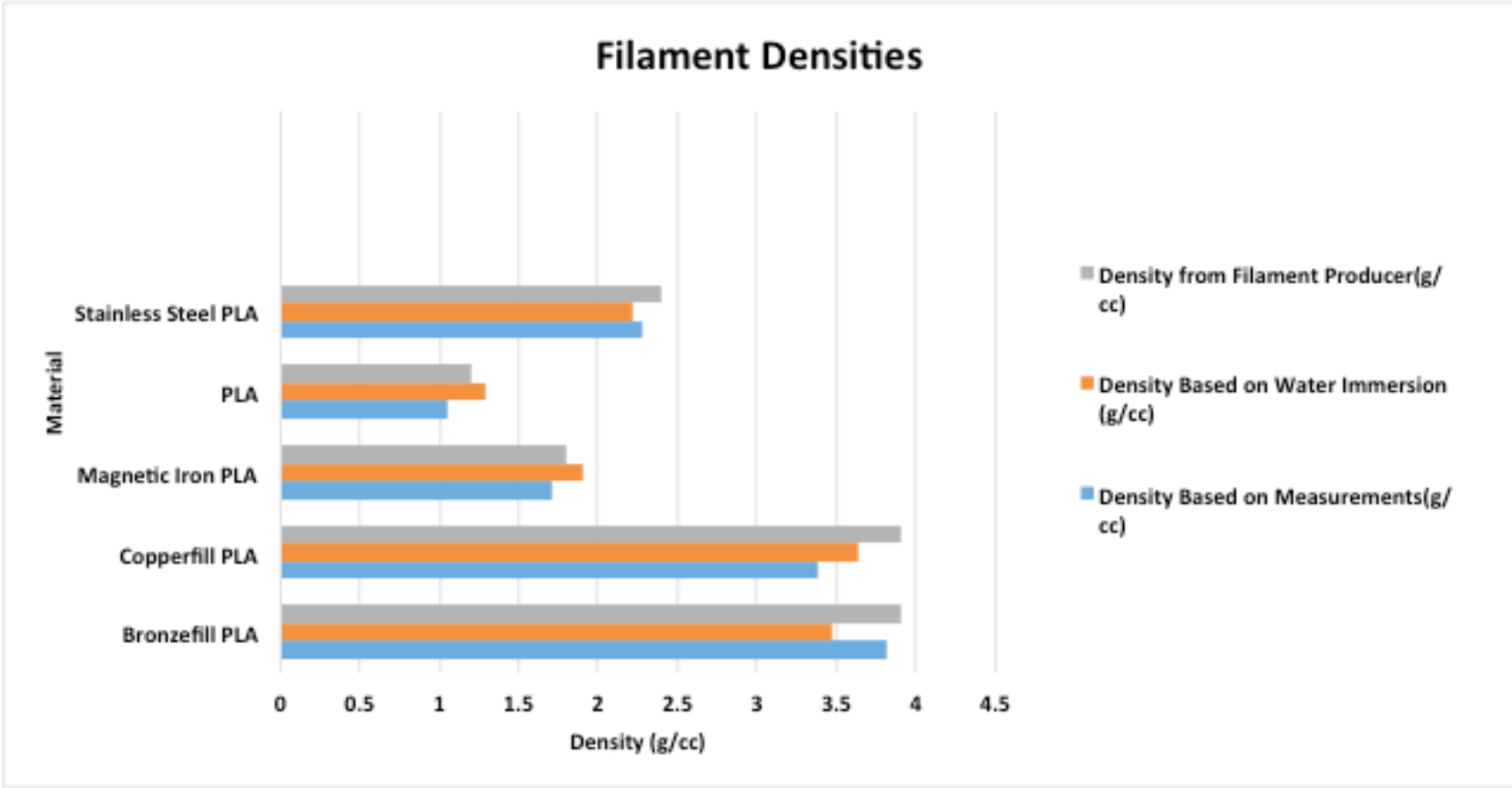


0.4mm



Density

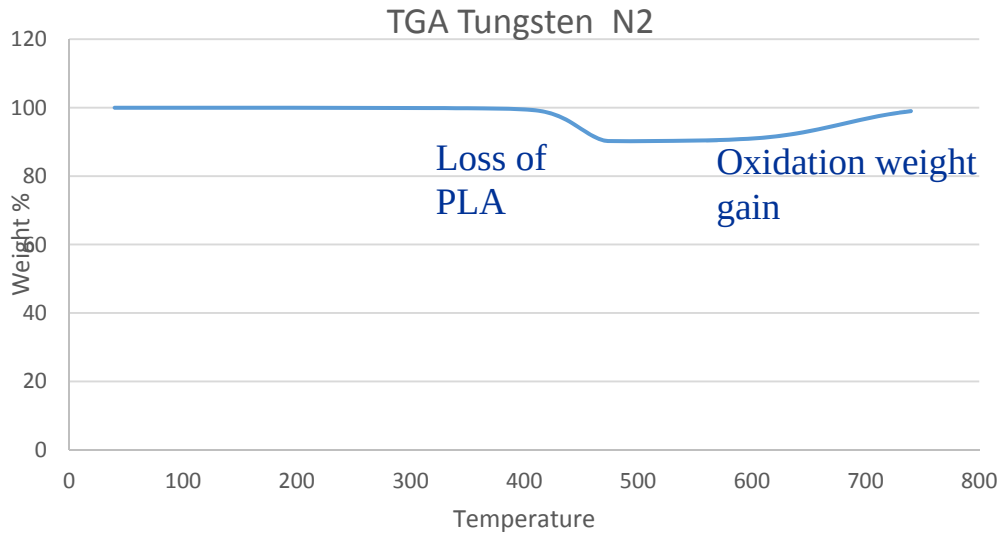
- **Metal Composite PLA vs. Pure PLA**
  - **The metal filled materials had much higher densities than the pure PLA; correlate to metal mass content.**

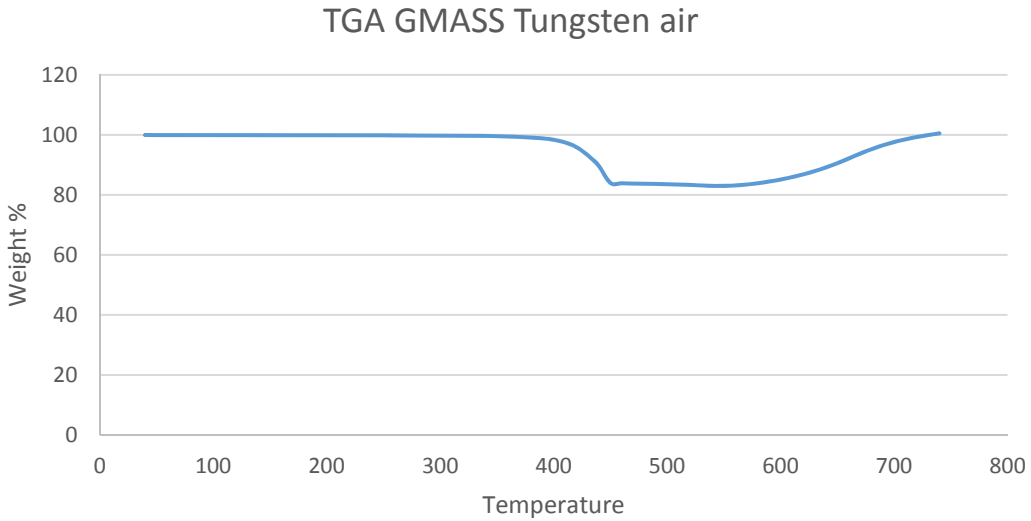


Thermogravimetric Analysis

Filament	***Metal Weight Percentage***	***Metal Volume Percentage***
Bronzefill PLA	80.35%	36.02%
Copperfill PLA	80.57%	36.41%
Stainless Steel PLA	58.87%	18.09%
Magnetic Iron PLA	48.33%	11.05%

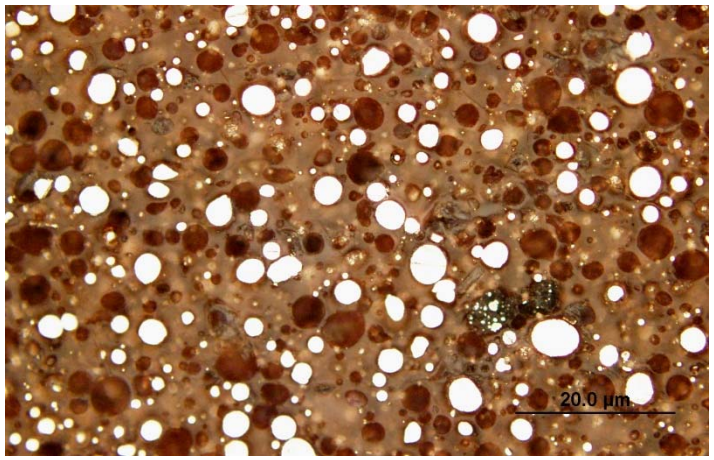
Thermogravimetric Analysis

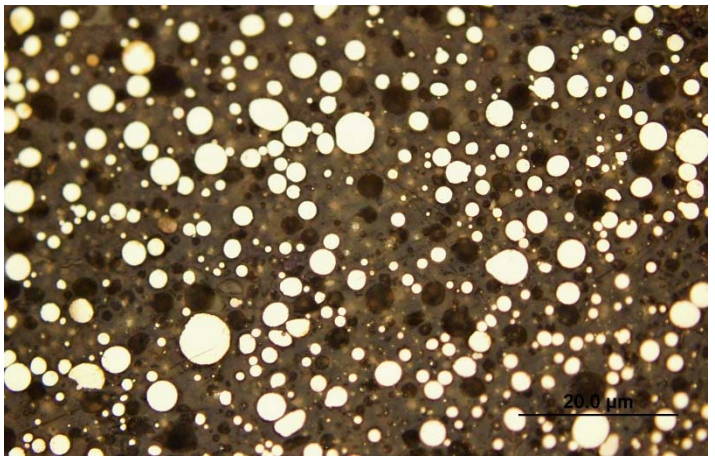




Microstructure

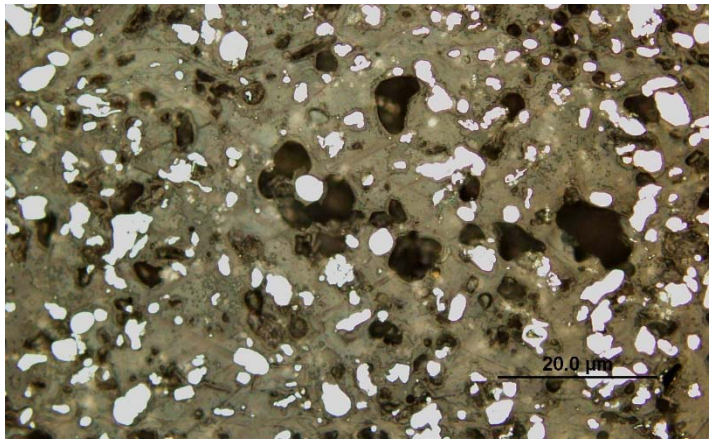
Copper PLA

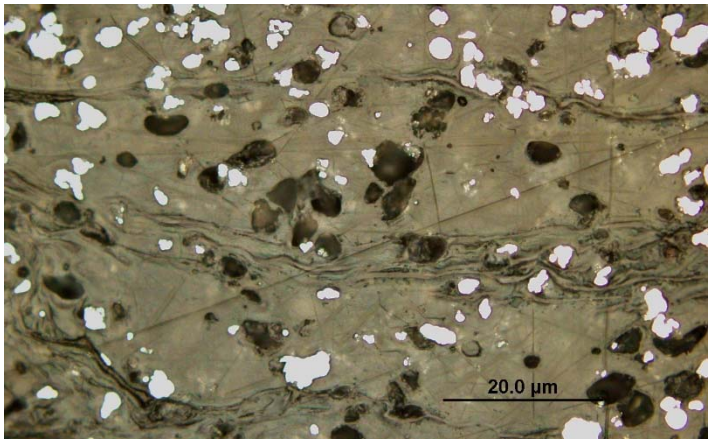




Bronze PLA

Stainless Steel PLA



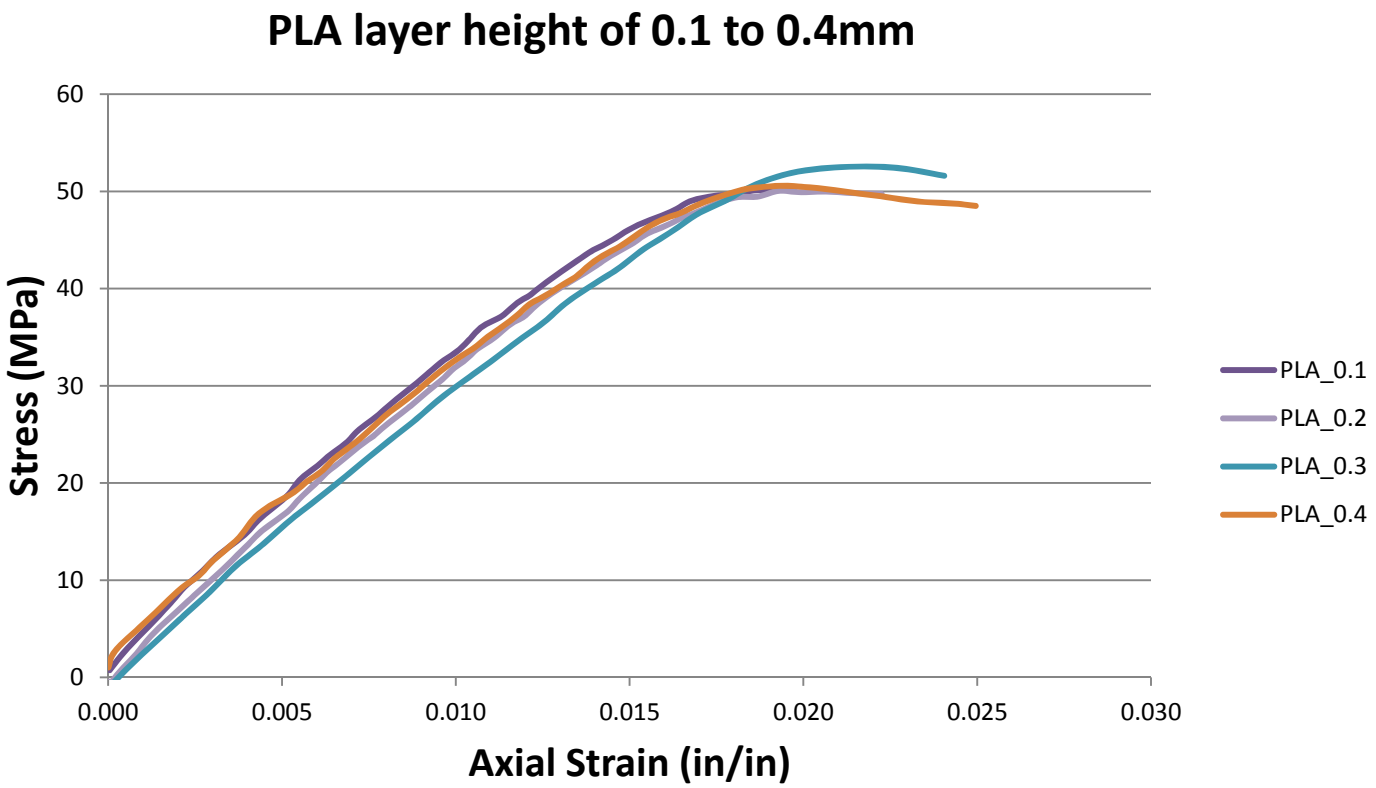


Magnetic Iron PLA

- Spheroidal Cu and bronze particles
- Deformed stainless and iron particles; poor dispersion!

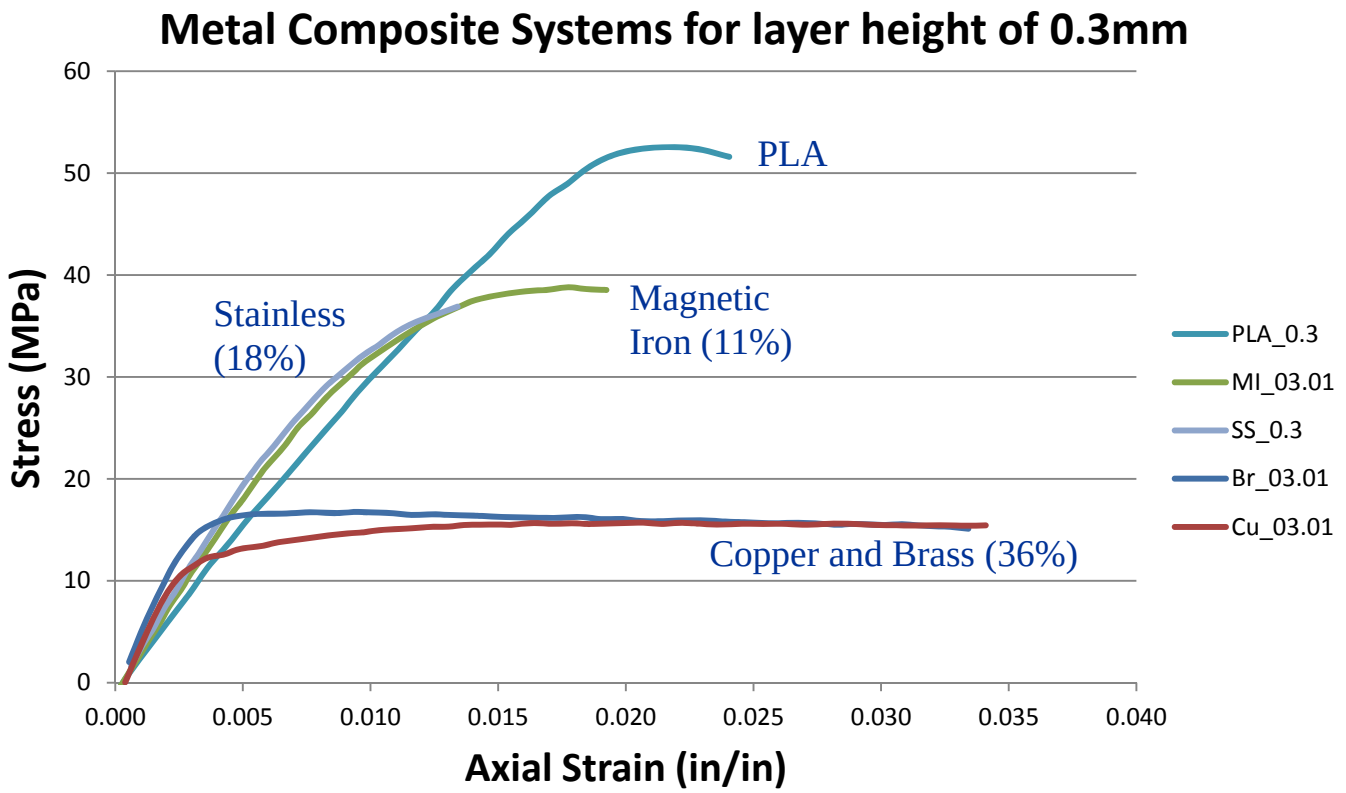
Tensile Data

- PLA shows no layer height effect:



Tensile Data

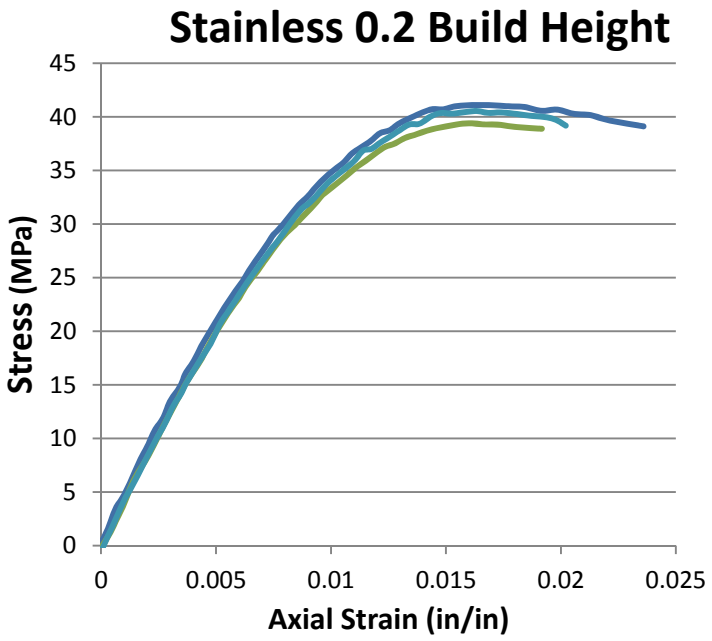
- PLA shows the greatest strength:

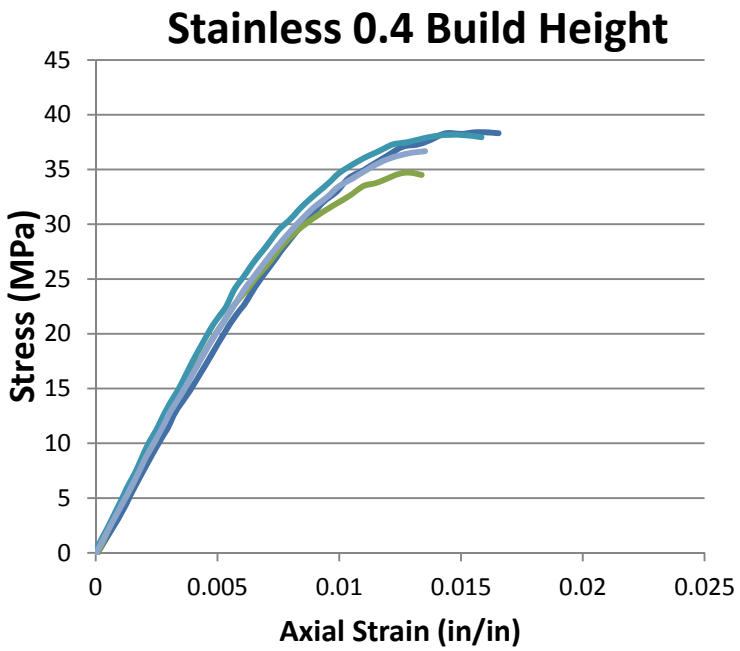


- As the concentration of metal in the filament increases, the strength decreases.

Tensile Data

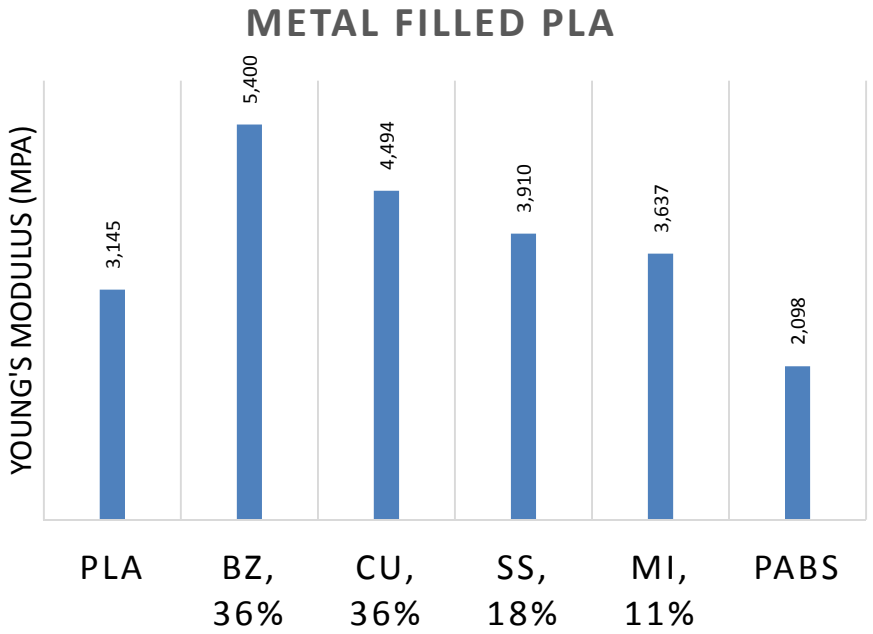
- Metal filled PLA show an effect of layer height:

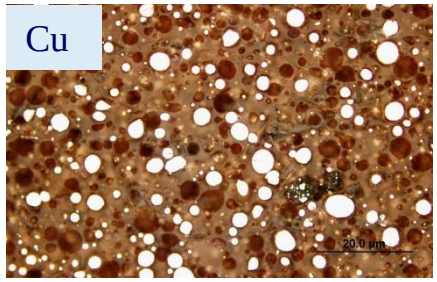




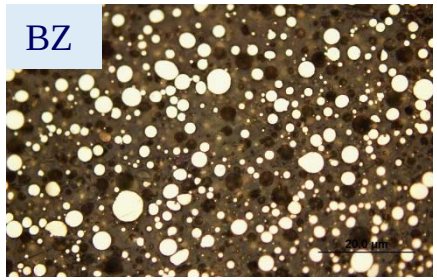
- Lower strength and strain to failure.

Young's Modulus





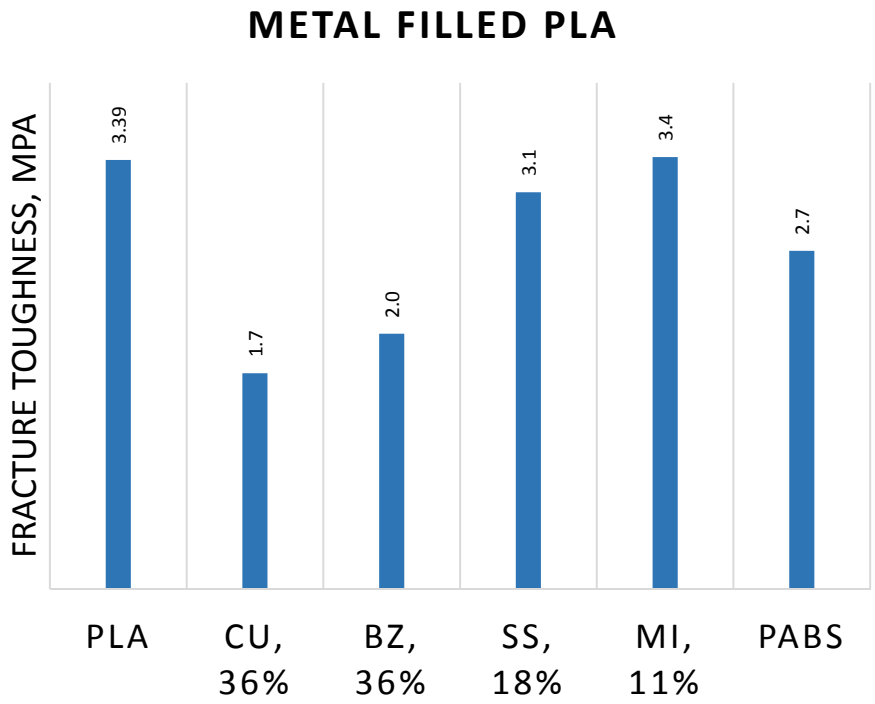
E_{Cu} = 117 GPa
(higher porosity)



E_{Bz} = 96-120 GPa

- Young's modulus follows the V% of metal - porosity.
- Still stiffer than premium ABS.
- Poisson's ratio was ~0.33.

Fracture Toughness



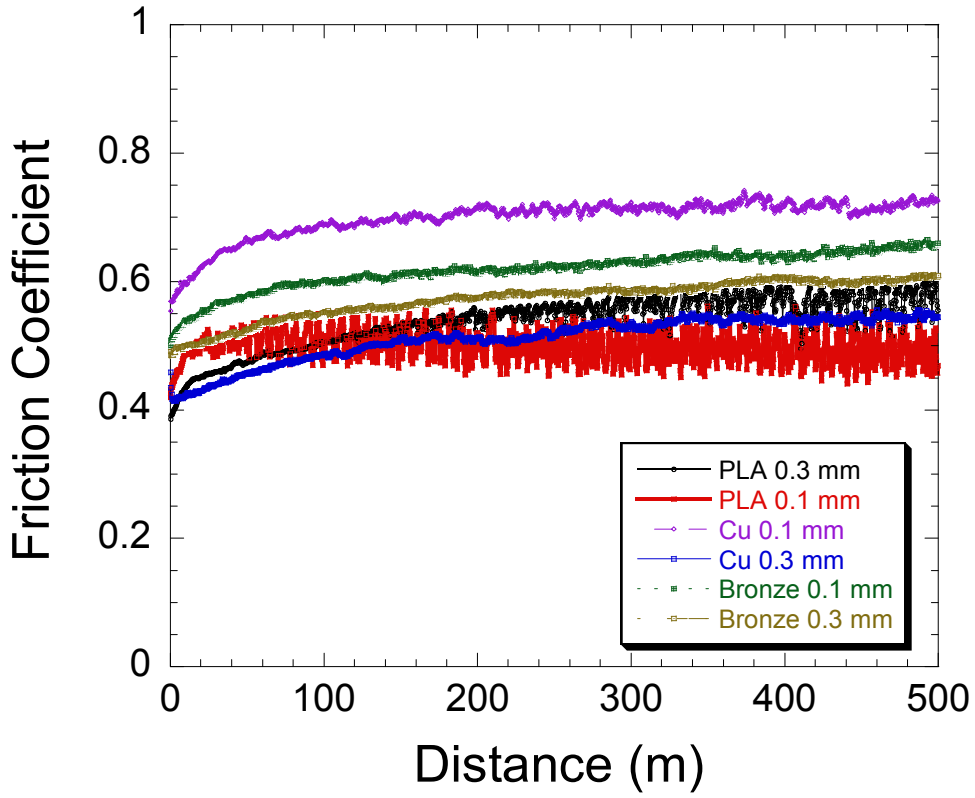
- Generally, the fracture toughness follows the V% of metal.
- PLA has greater toughness than ABS, but metal additions can lower significantly (50% for Cu).

Fracture Surfaces

- Do we have pictures?

Tribology

- **Friction Coefficient of metal filled PLA:**



Related talk to be given on wear etc.

  - The metal composite materials generally exhibit a higher coefficient of friction than pure PLA.
  - Higher layer height exhibits lower friction.

Conclusions

- PLA exhibits the greatest strength, with no dependence on layer height.
- Metal filled PLA is stiffer but weaker than unfilled; Good strain to failure is usually exhibited.
- SS filled PLA exhibits lower strain to failure – irregular powder and higher % fill. Bonding? Distribution? Surface finish? Fractography!
- As the metal volume percentage increases, the porosity increases, and lower strength is exhibited.
- Young's Modulus generally increase as the V% of metal increases.
- Fracture toughness decreases as metal content increases.
- Higher coefficient of friction is exhibited by metal filled PLA's.
- Metal powder act as a weak interface thereby lowering strength and toughness.

Future Work

- **Continuing to process tests, and analyze these metal filled PLA materials.**
- **Characterization of new filaments.**