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

Lily Kuentz¹, Anton Salem², M. Singh³, M.C. Halbig⁴, J.A. Salem⁴

¹Lake Ridge Academy, North Ridgeville, OH 44039
²Hawken School, Gates Mill, OH 44040
³Ohio Aerospace Institute, Cleveland, OH 44142
⁴NASA Glenn Research Center, Cleveland, OH 44135
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

- Three samples per condition

ASTM D638

ASTM D5045
• **Print resolution**
  - Prints of different layer heights exhibit different structures. Different mechanical properties?
Density

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

![Filament Densities Chart]

```
Material          Density from Filament Producer (g/cc) Density Based on Water Immersion (g/cc) Density Based on Measurements (g/cc)
----------------- ------------------------------------------------- ------------------------------------------------- -------------------------------------------------  
Stainless Steel PLA                       3.0                          3.1                          3.2
PLA                                          2.5                          2.6                          2.7
Magnetic Iron PLA                           3.5                          3.6                          3.7
Copperfill PLA                              3.0                          3.1                          3.2
Bronzefill PLA                              3.5                          3.6                          3.7
```

Density (g/cc)

- 0
- 0.5
- 1
- 1.5
- 2
- 2.5
- 3
- 3.5
- 4
- 4.5
## Thermogravimetric Analysis

<table>
<thead>
<tr>
<th>Filament</th>
<th>Metal Weight Percentage</th>
<th>Metal Volume Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronzefill PLA</td>
<td>80.35%</td>
<td>36.02%</td>
</tr>
<tr>
<td>Copperfill PLA</td>
<td>80.57%</td>
<td>36.41%</td>
</tr>
<tr>
<td>Stainless Steel PLA</td>
<td>58.87%</td>
<td>18.09%</td>
</tr>
<tr>
<td>Magnetic Iron PLA</td>
<td>48.33%</td>
<td>11.05%</td>
</tr>
</tbody>
</table>
Thermogravimetric Analysis

TGA Tungsten N2

Loss of PLA

Oxidation weight gain

TGA GMASS Tungsten air
Microstructure

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

- PLA shows no layer height effect:

![Graph showing PLA layer height of 0.1 to 0.4mm](image)
Tensile Data

• PLA shows the greatest strength:

![Graph showing metal composite systems for layer height of 0.3mm](image)

- Stainless (18%)
- Magnetic Iron (11%)
- Copper and Brass (36%)

• 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.

![Stainless 0.2 Build Height](image)

![Stainless 0.4 Build Height](image)
• Young’s modulus follows the V% of metal - porosity.
• Still stiffer than premium ABS.
• Poisson’s ratio was ~0.33.

\[
\begin{align*}
E_{Cu} &= 117 \text{ GPa} \\
E_{Bz} &= 96-120 \text{ GPa}
\end{align*}
\]
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?
• Friction Coefficient of metal filled PLA:

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

Related talk to be given on wear etc.
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.