Correlation of ULTEM 9085 Physical, Chemical, and Mechanical Properties

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Motivation, Objective, and Approach

• Motivation and Key Issues
  – Obtain a better understanding of how the physical and chemical properties of AM ULTEM 9085 affect the mechanical performance

• Objective
  – Identify abnormal performance of AM ULTEM 9085 samples and develop theories for mechanical testing

• Approach
  – Review initial statistical analysis and further explore the data set
  – Development of theories for abnormal ULTEM 9085 performance
  – Print and test AM ULTEM 9085 coupons to explore theories
Correlation of ULTEM 9085 Physical, Chemical, and Mechanical Properties

- Principal Investigator & Researchers
  - John Parmigiani (PI); OSU faculty
  - Seth O’Brien; OSU grad student
- FAA Technical Monitor: Danielle Stephens
- FAA Sponsor: Cindy Ashforth
- Other FAA Personnel Involved: Larry Ilcewicz
- NIAR/NCAMP Personnel Involved
  - Royal Lovingfoss
  - Elizabeth Clarkson
- Industry Participation
  - Charles Evans; Stratasys
Today’s Topic

ULTEM 9085 Qualification and FDM Background
Project Steps
Literature Review
Abnormal Performance in Qualification
Further Analysis of Qualification
Abnormal Performance Theories
Intial Testing Plan
• ULTEM 9085
  – Polyetherimide and polycarbonate amorphous thermoplastic
  – Strength-to-weight ratio (480.5 lb-in/g)
    ▪ ABS 379.3 lb-in/g
    ▪ PLA 378.3 lb-in/g
    ▪ Nylon 610.9 lb-in/g
  – Flame, smoke, and toxicity (FST) characteristics
  – Currently used in aerospace and transportation sectors
ULTEM 9085 Qualification Background

• Planned and tested between 2016-2019 for the first PBAM qualification
• Fabricated by RP+M
• Tested at NIAR
• Analyzed by NCAMP statistician
Qualification Parameters

- 1 contour
- ±45° raster pattern
- 0” air gap
Project Steps

- Identify abnormalities between orientations from initial analysis
- Analyze other sections of data
- Develop theories for abnormalities
- Test printed coupons to support theories
• **X orientation** has the lowest density of all orientations
  – Attributed to the contour-to-raster ratio [3]
• **Tensile strength**: \( Y > X > Z_{45} > Z \)
  – Layers parallel to load direction = higher strength [4]
• **Inter/intra layer necking effects mechanical properties**
  – Relates to layer temperature at time of deposition [5]
# Abnormal Performance in Qualification

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Condition</th>
<th>Results</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dogbone Tension, 0.2% Offset Yield Strength</td>
<td>CTD</td>
<td>X, Z, Z45 combined</td>
<td>Not expected, X&gt;Z,Z45</td>
</tr>
<tr>
<td></td>
<td>ETW</td>
<td>X, Z, Z45 combined</td>
<td>Not expected, X&gt;Z,Z45</td>
</tr>
<tr>
<td></td>
<td>RTD</td>
<td>X, Z combined</td>
<td>Not expected, X&gt;Z</td>
</tr>
<tr>
<td>Filled-Hole Tension, Strength</td>
<td>RTD</td>
<td>X, Z combined</td>
<td>Not expected, X&gt;Z</td>
</tr>
</tbody>
</table>
## Yield Strength Literature Comparison

<table>
<thead>
<tr>
<th>Source</th>
<th>Yield Strength ksi for Print Orientations</th>
<th>Replicates per Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y</td>
<td>X</td>
</tr>
<tr>
<td>NCAMP (RTD)</td>
<td>6.56</td>
<td>5.54</td>
</tr>
<tr>
<td>[4]</td>
<td>7.94</td>
<td>6.81</td>
</tr>
<tr>
<td>[5]</td>
<td>5.30</td>
<td>4.32</td>
</tr>
</tbody>
</table>

Other two studies showed that X>Z for yield strength


Further Analysis-Moisture Loss

X had higher moisture loss for all tests
Further Analysis-Specimen Density

- Lower density = higher porosity
- With print orientation shown, interesting that X, Y, and Z would be significantly different
X Orientation Theory

A combination of

• higher void percentage
• less fusion between intra-inter layers due to area of layers

leads lower performance of X orientation
# Initial Testing Plan

<table>
<thead>
<tr>
<th>Abnormality</th>
<th>Test/Analysis</th>
<th>Orientation</th>
<th>Condition</th>
<th>Samples per Orientation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in cube densities</td>
<td>Relative Density</td>
<td>X, Y, Z</td>
<td>RTD</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Retesting for yield and ultimate strength</td>
<td>Dogbone Tension (D638)</td>
<td>X, Y, Z</td>
<td>RTD</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Coalances of layers and void percentage</td>
<td>Microstructure/ Macrostructure</td>
<td>X, Y, Z</td>
<td>N/A</td>
<td>5 50% printed</td>
<td>15</td>
</tr>
<tr>
<td>X orientation angles leading to differing strengths</td>
<td>Dogbone Tension (D638)</td>
<td>X0, X45, X90</td>
<td>RTD</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Coalances of layers and void percentage</td>
<td>Microstructure/ Macrostructure</td>
<td>X0, X45, X90</td>
<td>N/A</td>
<td>5 50% printed</td>
<td>15</td>
</tr>
</tbody>
</table>

- One sample for each test printed at one of the 5 locations in printer
  - Reduce thermal gradient effect on samples
  - Consistent time between layer deposition
Questions and comments are encouraged!

Thank you!
References


