Exit Presentation: Infrared Thermography on Graphite/Epoxy

By
Kayla Comeaux
Agenda

• Personal Information
• Project
  – Objectives
  – Flat bottom hole simulation
  – Flat bottom hole experiment
  – Thin delamination simulation
• Summary
  – Skills acquired
  – Future work
  – Experiences at JSC
  – After Graduation
  – Acknowledgments
Personal Information

- Hometown: Friendswood, Texas
- University: Southwestern University
- Major: Mathematics
- Minor: Physics, Economics
- Pi Mu Epsilon, Chi Alpha Sigma, Pi Theta Kappa
- Soccer, Lacrosse, Choir, Tutoring
- MUST Intern
Project Objectives

- Simulate Flash Thermography on Graphite/Epoxy Flat Bottom hole Specimen and thin void specimens.

- Obtain Flash Thermography data on Graphite/Epoxy flat bottom hole specimens

- Compare experimental results with simulation results

- Compare Flat Bottom Hole Simulation with Thin Void Simulation to create a graph to determine size of IR Thermography detected defects
Composite Dimensions

Diagram showing composite dimensions with annotations such as 0.25" DIA FLAT BOTTOM HOLE, 24 PLACES, 9.25" length, 2.75" width, and various distances and measurements.
Composite Dimensions
Composite Dimensions

[Image of composite dimensions with a grid and labeled points A, B, C, and D.]
Creating Flat Bottom Hole Simulation

• Simulation requirements
  – Uniform thickness
  – Defects completely inside composite

• Pixel size
  – Circular defects to square defects
  – Width in terms of pixels

<table>
<thead>
<tr>
<th>Thermal Properties of Composite</th>
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<tbody>
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<th>Thermal Properties of air</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.20(kg/m³)</td>
</tr>
<tr>
<td>Heat Capacity</td>
<td>1005(J/kg/K)</td>
</tr>
<tr>
<td>Conductivity: Z axis</td>
<td>0.026(W/m/K)</td>
</tr>
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<td>0.026(W/m/K)</td>
</tr>
<tr>
<td>Conductivity: Y axis</td>
<td>0.026(W/m/K)</td>
</tr>
</tbody>
</table>
### Specimen
- **Length**, $L_x$, [m]: 0.1115
- **Width**, $L_y$, [m]: 0.064
- **Heat exchange coef. front surface**, $h_F$, [W/(m²°C)]: 10
- **Heat exchange coef. rear surface**, $h_R$, [W/(m²°C)]: 10
- **Steps along X**: 223
- **Steps along Y**: 128
- **Number of layers**, $i$: 1
- **Number of defects**: 4
- **Length of each step in X**, [m]: 5.000E-04
- **Length of each step in Y**, [m]: 5.000E-04
- **Total thickness**, $L_Z$, [in]*: 0.000

### Layers
- **Layer #1**
  - **Conductivity**, $K_x$, [W/(m°C)]: 0.023557
  - **Conductivity**, $K_y$, [W/(m°C)]: 0.023557
  - **Conductivity**, $K_z$, [W/(m°C)]: 0.0043267
  - **Heat capacity**, $C$, [J/(kg·K)]: 870.8544
  - **Density**, $r$, [kg/m³]: 1576.2045
  - **Thickness**, $L_z$, [m]: 1.118E-03
  - **Number of steps along Z**, $n$: 22
  - **Thickness of each step in Z**, [m]: 5.080E-05
  - **Thickness of each step in Z**, [in]*: 0.002

### Heat Source
- **Max heat pulse**, $Q$, [W/m²]: 1.800E+06
- **Ambient temperature**, $T$, [°C]: 30
- **Initial temperature**, $T_i$, [°C]: 30
- **Coeff. of spatial distribution in X**, [1/m²]: 0
- **Coeff. of spatial distribution in Y**, [1/m²]: 0
- **Heat source center in X**, [m]: 0
- **Heat source center in Y**, [m]: 0

### Timing
- **Type**: Square Pulse
- **Heat time**, $\tau_h$, [s]: 0.005
- **End time**, [s]: 6
- **Time step**, [s]: 0.005

### Output
- **Output time step**, [s]: 0.01
- **Surface**: Front
<table>
<thead>
<tr>
<th>Thermal Properties of Defects</th>
<th>Defect A</th>
<th>Defect B</th>
<th>Defect C</th>
<th>Defect D</th>
<th>End of Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity, $K_x$, [W/(m.$^\circ$C)]</td>
<td>0.026</td>
<td>0.026</td>
<td>0.026</td>
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<tr>
<td>Conductivity, $K_y$, [W/(m.$^\circ$C)]</td>
<td>0.026</td>
<td>0.026</td>
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<tr>
<td>Heat capacity, $C$, [J/kg.$^\circ$K]</td>
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<td>Density, $r$, [kg/m$^3$]</td>
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<tr>
<td>Length, $L_x$, [m]</td>
<td>5.500E-03</td>
<td>5.500E-03</td>
<td>5.500E-03</td>
<td>5.500E-03</td>
<td></td>
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<tr>
<td>X initial point, [m]</td>
<td>2.950E-02</td>
<td>5.000E-02</td>
<td>7.050E-02</td>
<td>9.100E-02</td>
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<tr>
<td>Width, $L_y$, [m]</td>
<td>5.500E-03</td>
<td>5.500E-03</td>
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<tr>
<td>Y initial point, [m]</td>
<td>2.950E-02</td>
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<tr>
<td>Thickness, $L_z$, [m]</td>
<td>6.096E-04</td>
<td>7.620E-04</td>
<td>7.620E-04</td>
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<tr>
<td>Z initial point, [m]</td>
<td>5.080E-04</td>
<td>3.556E-04</td>
<td>3.556E-04</td>
<td>3.556E-04</td>
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</tr>
</tbody>
</table>
Flat Bottom Hole Simulation: Column 1

- Simulation size
Data from Flat Bottom Hole Simulation: Column 1

Infrared Thermography Simulation of 0.044 Inch Thick Graphite/Epoxy Composite

Max 2.751 K

Min 2.241 K

Center of Defect D

Center of Defect C

Center of Defect B

Center of Defect A

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Simulation Results: Temperature v. Time Image

- Shows the difference in temperature.
- Blue curve is reference point.
- X, Y : Coordinates defect’s center on simulation.

<table>
<thead>
<tr>
<th>Num</th>
<th>x</th>
<th>y</th>
<th>Color</th>
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<td>1</td>
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<td>2</td>
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<td>5</td>
<td>188</td>
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</table>

Number of output time steps (Output time step 0.010000s)

Temperature Rise (K)

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Normalizing Data and Graphing

- Collect data from Temperature v. Time graph
- Convert text file to excel spreadsheet
- Normalized contrast:
  \[
  \frac{(T_i - T_{i0}) - (T_r - T_{r0})}{(T_i - T_{i0}) + (T_r - T_{r0})}
  \]
  \(T = \) Temperature for simulation,
  Pixel intensity for experimental IR data
Experimental Set-up
Experimental Data

- Reference point
- Point of Interest
- Different sizes

Image Window: Flat Bottom Hole

Defect B2
Simple Contrast

- Finding maximum simple contrast
- Saving data as text file
- Transporting data to Excel
- Creating Normalized contrast

Flat Bottom Hole Contrast Evolution

![Graph showing contrast evolution with peak contrast and time values.]

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Calculating and Graphing Normalized Contrast

- Average pre-flash temperatures for both reference point and point of interest
- Use averages as initial temperature

<table>
<thead>
<tr>
<th>Time</th>
<th>Reference Point</th>
<th>Point of Interest</th>
<th>Reference Point*</th>
<th>Point of Interest*</th>
<th>Normalized Contrast</th>
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<td>-0.15</td>
<td>7240</td>
<td>7249</td>
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<td>-0.133</td>
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<tr>
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<tr>
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<td>0.017</td>
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<td>9758</td>
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<td>2507.222</td>
<td>-0.00494</td>
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</table>
Comparison and Correction of Simulation

- The Normalized contrast for the original simulation and experimental data
- Analysis
- Peak Contrast
- Peak Time
- Correction of simulation data to more accurately portray experimental data

Normalized Contrast: Defect A1

Normalized Contrast vs. Time (s)

Simulation
Experiment

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Correction of Simulation

• Diffusivity: $\alpha = \frac{\kappa}{(\rho \times C)}$

• Change properties of material
  – Change Specific Heat
  – Change in Conductivity
  – Could change Density

• Final Decision

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<th>Final Values</th>
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Simulation Data: Defect B1

Normalized Contrast vs. Time (s)

Heat Capacity times 0.05
Corrected Simulation

- Corrected simulation
- Comparison between original simulation, corrected simulation, and experimental data

Normalized Contrast: Defect A1

Normalized Contrast

- Corrected Simulation
- Original Simulation
- Experimental

Normalized Contrast

Time (s)

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Sources of Differences

- Simulation contrast is based on temperature versus time. Experimental contrast is based on pixel intensity versus time.
- Experimental Flash vs. Simulation Flash
  - Experimental flash envelope has a sharp rise and slow decay
  - Simulation flash is a square pulse
- Experimental factors
  - Experimental data is more sensitive to pixel size. Get smaller pixel intensity for a larger pixel
  - Uneven flash causes some lateral heat flow
  - Part has a surface texture causing lateral heat flow
- Emissivity
  - The specimen emissivity was measured to be 0.9 and provides lower (< 5%) experimental contrast
- Simulation inaccuracies (model approximations, boundary condition approximations, no lateral heat flow)
Creating Thin Delaminations

- Change depths of the defects, but leave the initial points unchanged.

- Input data into ThermoCalc-6L

- Run simulation

Flat Bottom Hole Simulation:

Thin Delamination Simulation:
• Same as for the flat bottom hole simulation
  – Collect data from Temperature v. Time graph for each defect
  – Convert the text file to excel spreadsheet compatible
  – Generate normalized contrast graph
Comparison of Simulations

• Comparing flat bottom hole simulation to thin delamination simulation

• Compare and graph the peak contrast ratio and peak time ratio
  – Thin delamination/Flat bottom hole
Peak Contrast Ratio and Peak Time Ratio

Graph of Peak Time Ratio vs. Peak Contrast Ratio for Graphite/Epoxy Composite

- .5 mil thickness
- 2 mil thickness
- 6 mil thickness
- 10 mil thickness
- 20 mil mil thickness
- 70.4 mil thickness

Equation: \( y = -8.9195x^2 + 18.262x - 8.3551 \)

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Future Work

• Make controlled impacts to make thin delaminations
• Evaluate delaminations with Infrared Thermography
• Evaluate delaminations with Ultrasonic Techniques
• Section the specimen at delaminations
• Determine actual size of delaminations
• Compare actual results with simulated results
• Determine accuracy of the simulation
Skills Acquired

• Learned Thermodynamics
  – Theory and application
    • IR temperature measurement
• Infrared Thermography NDE
  – Simulation
  – IR Experimental data acquisition and analysis
• Eddy Current
• Ultrasonic Testing
• Time management
• Work hours
• Technical paper

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Experiences at JSC

- Building 14: Boom Tower
- Ellington Field: Guppy
- Building 1: ONWG Meetings
- Volunteering: Food Bank
- Movie Night
- Mission Control: Apollo
- NBL
- MLS All-Stars vs...
- Tutoring: CLPC Day of Service
- Musicals

K. Comeaux, Summer 2010
Acknowledgements

• Parents and Family
• Mentors: Ajay Koshti & David Stanley
• Ovidio Olveras, Eddie Pompa, Norman Ruffino, Rodrigo Devivar, John Figert, Budd Castner, Mike Kocurek, Denise Plantier, Erica Worthy, Joseph Prather
• MUST Point of Contact: Cornelius Johnson
Thank You