Adhesive Bonding of Aluminum and Copper in HVAC&R Applications

Oak Ridge National Laboratory
Patrick Geoghegan, PhD.
geogheganpj@ornl.gov
**Project Summary**

**Timeline:**
Start date: 10/1/2016  
Planned end date: 3/1/2020

**Key Milestones**
1. M18 – meet 75% of joint strength requirements  
2. M27 – Meet full strength and leakage requirements

**Budget:**

**Total Project $ to Date:**
- DOE: $450K  
- Cost Share: $*

**Total Project $:**
- DOE: $1,500K  
- Cost Share: *

* In-kind contribution from CRADA partner – exceeds DOE funding level; exact total is confidential information

**Key Partners:**

![3M Logo]

**Project Outcome:**
Aluminum-Copper, Aluminum-Aluminum, and Copper-Copper adhesive joints that supplant traditional brazing in HVAC&R applications. Reduce heat exchanger production cost by 30-40% compared to controlled atmosphere brazing. More compact, lighter units requiring less refrigerant charge.
Team

Patrick Geoghegan, PhD.
Principal Investigator

Adrian Sabau, PhD.
Materials Science R&D Staff

Shari Loushin
Lead Application Engineering Specialist

Matthew Kryger, PhD.
Research Polymer Scientist

Eckhard A. Groll
Reilly Professor of Mechanical Engineering & Associate Dean of Undergraduate and Graduate Education, College of Engineering

Haotian Liu
Ph.D. Student

Justin A. Weibel
Associate Professor of Mechanical & Associate Director of the Cooling Technologies Research Center (CTRC)

Expertise in building equipment, neutron radiography, material characterization and functionality

World leaders in adhesives

Renowned graduate program
Challenge

- According to the 2016 Annual Energy Outlook, the U.S. consumed 2.15 Quads in delivered energy in cooling, refrigeration & freezing across the residential and commercial sectors.

R&D Opportunities for Joining Technologies in HVAC&R, BTO, October 2015

- Reduce refrigerant leakage
- Increase lifetime equipment operating efficiency and reliability
- Decrease equipment production cost
- Enable new designs not feasible with brazing

After ETSU (1997), Cutting the cost of refrigerant leakage, Good Practice Guide 178, Energy Technology Support Unit, Didcot, UK.

www.homeadvisor.com
Approach – Adhesive Bonding

Develop adhesives with specific chemistries for bonding to aluminum and copper

Enhanced surface preparation (laser structuring, etc.) and characterization (XPS, SEM, etc.)

Structural analysis and optimization, and non-destructive coverage quantification via neutron imaging

UL207, ASHRAE 15, ISO 14903, etc.
Prototype Testing
Strong business model
Adhesive Approach

- Develop adhesives with specific chemistries for bonding Al and Cu
- Performance Characterization (overlap shear strength and peel strength at 2-3 temperatures)
- Basic rheology characterization of viscosity and modulus vs. time for strength build
- Characterization of glass transition temperature

Milestone – Formulation and characterization of 3-5 adhesives, M15

### 1K Epoxy
- **Pros**
  - No mixing
  - Better high temp performance
  - Unlimited open time
- **Cons**
  - Heat cure
  - Poor room temperature stability (cold storage/transportation)
  - Nevertheless, some customers using this now for braze replacement.

### 2K Epoxy
- **Pros**
  - Room temperature stable
  - Room temperature curable
  - High toughness and fatigue
- **Cons**
  - Mixing required (difficult at low volumes)
  - Poor high temperature performance (can improve with heat curing)
  - Finite nozzle life and open time
Adhesive Approach – Improved 1K epoxy

Materials in development

- Minimal increase in viscosity over time
- Good high temperature performance
- Improved thermal properties compared to past 2k brazing materials
- Fatigue testing in progress

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Tg (DSC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental A</td>
<td>121 °C</td>
</tr>
<tr>
<td>Experimental B</td>
<td>131 °C</td>
</tr>
<tr>
<td>Experimental C</td>
<td>141 °C</td>
</tr>
</tbody>
</table>
Surface Preparation Approach – Laser structuring

Samples with different laser structuring conditions

2D surface profile with profilometry
Quantitative Coverage – Neutron Imaging

In-situ curing

Laplacian of Gaussian

scikit-image.org
http://dx.doi.org/10.7717/peerj.453
Adhesive Characterization driving ABAQUS modeling

- Epoxy adhesive with cohesive failure:
  - Fracture toughness: Double cantilever beam (DCB) test; End-notched flexure (ENF) test
  - DCB samples will be prepared similarly as for previous studies at Purdue University
  - Elastic/shear modulus: tensile/shear test


Optimized flare geometry

Failure mechanism at the interface
Road Map: Fatigue prediction of tube-in-tube joint

1) Proposed adhesive bonded tube-in-tube joint.
   - DP460NS adhesive
   - Temp cycling: -55 to 80°C
   - Many hours per cycle
   - Can joint last > 1000-10000 cycles?

2) Obtained and measured tensile & CTE properties of adhesive & tubes

3) Created & ran FEA model of joint:
   - Hoop stress at -55°C ~ 85% of fail
   - Unaffected by joint design
   - Radial stress at -55°C ~ 15% of fail
   - Affected by bond & tube thickness
   - Ambiguous modeling results

4) Measured fatigue properties
   (Measurements of DP460NS by CNRC Chicoutimi, funded by 3M)

5) Modeled fracture properties in joint using 3M developed self-steering crack growth model:

6) Combined measurement & model results to make assessment:

   Analysis Conclusion:
   - Stress driven energy release rate below fatigue threshold for comparable temperatures.
   - Possible initiation of small crack at -55°C end but not enough energy to drive propagation
   - Joint should last. Some design refinement would improve safety factor.

Postlude: Joint cycled >1000 cycles possibly more with no failures.
Approach – System demonstration

- Test stand at Herrick Labs, Purdue University
  - Monitored with pressure transducers and thermocouples
  - Pressure hold test
  - System operating test
  - Variant pressure operating test

- Schematic figure of the system

- Mechanical testing of joints according to relevant standards
- Standards ISO 14903, ASHRAE 15, UL207, etc.
**Stakeholder Engagement**

- Approximately 40 HVACR-M companies contacted and with response and varying levels of engagement

<table>
<thead>
<tr>
<th>Braze suppliers</th>
<th>Aluminum Microchannel heat exchanger manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flaring equipment</td>
<td>AC Equipment Manufacturers</td>
</tr>
<tr>
<td>manufacturers</td>
<td></td>
</tr>
<tr>
<td>Potable water/ chillers</td>
<td>Brazed plate heat exchanger manufacturers</td>
</tr>
</tbody>
</table>

- On-site visits ongoing to manufacturing plants
- Initial samples formulated for preliminary evaluation
Stakeholder engagement

Summary of feedback

• Value proposition especially for hand brazers under development
• Potential for Automation appealing
• Large OEMs most interested in the final heat exchanger design
• Working within the limitations set by flaring equipment manufacturers

Focus

• Aluminum microchannel heat exchanger to copper tube connection
• Copper to copper U bends
• New heat exchanger concepts, particularly for aluminum heat exchangers
• Refrigerant Compatibility
Stakeholder Engagement

• HVAC&R Manufacturer engagement to determine needs for adhesive performance and application methods/cure methods (ongoing site visits)
• Evaluate market attractiveness based upon HVAC&R-M feedback through customer evaluations – manufacturers are aiding the cost analysis
• Application and surface preparation expertise to HVAC&R-M
Progress

3 year project

M18 – meet 75% of joint strength requirements

M27 – meet full strength and leakage requirements

M36 - Deliver Tech to Market Plan and New Product literature

Prototype testing

Geometry optimization

Neutron Imaging Testing

Surface Preparation

Coupon Testing

Adhesive Formulation
Thank You

Oak Ridge National Laboratory
Patrick Geoghegan, PhD.
geogheganpj@ornl.gov
REFERENCE SLIDES
Project Budget: DOE Total $1500K  
Variance: Project delayed until 3/1/2017 due to contract negotiations  
Cost to Date: $450K  
Additional Funding: None

<table>
<thead>
<tr>
<th>Budget History</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE</td>
</tr>
<tr>
<td>$250K</td>
</tr>
</tbody>
</table>
Project Plan and Schedule

## Project Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Past Work</th>
<th>Current/Future Work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Past Work

<table>
<thead>
<tr>
<th>Task</th>
<th>FY2017</th>
<th>FY2018</th>
<th>FY2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 Milestone: DMP and IPMP</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>Q2 Milestone: Surface Preparation</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>Q3 Milestone: Joint strength Assessment</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>Q4 Milestone: Gauge HVAC&amp;R Interest</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
</tr>
</tbody>
</table>

### Current/Future Work

<table>
<thead>
<tr>
<th>Task</th>
<th>FY2017</th>
<th>FY2018</th>
<th>FY2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 Milestone: Preliminary Cost Analysis of current brazing processes</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>Q2 Go/No Go: Assessment of adhesive and surface combination</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>Q3 Milestone: Joint Coverage through Neutron Imaging</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
<td>![Symbol]</td>
</tr>
</tbody>
</table>