Adhesive Bonding of Aluminum and Copper in HVAC&R Applications

Oak Ridge National Laboratory
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Project Summary

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

Key Milestones
1. M24 – meet 75% of joint strength requirements
2. M33 – meet full strength and leakage requirements

Budget:
Total Project $ to Date:
• DOE: $1,500K
• Cost Share: $*

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• DOE: $1,500K
• Cost Share:*

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

Key Partners:

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Project Outcome:
• Aluminum-copper, aluminum-aluminum, and copper-copper adhesive joints that supplant traditional brazing in HVAC&R applications
• Heat exchanger production cost reduced by 30–40% compared with 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

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

3M:
World leaders in adhesives

Purdue University:
Renowned graduate program

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

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

Haotian Liu
PhD Student
Challenge

• According to the 2016 Annual Energy Outlook, the United States consumed 2.15 Quads in delivered energy in cooling, refrigeration, and 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
Approach — Adhesive Bonding

Develop adhesives with specific chemistries for bonding to aluminum and copper

- UL207, ASHRAE 15, ISO 14903, etc.
- Prototype testing
- Strong business model

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

Structural analysis and optimization and non-destructive coverage quantification via neutron imaging
Braze Replacement Adhesive — Concepts

Subassembly manufacturing

Heat exchanger (tube & fin) manufacturing

U-bend attachment

Header attachment

Unit assembly connections

• U-bend receptacle or robotic dispense with
  – Upright heat bank cure
  – Room temp cure
  – UV trigger cure

• Solid ring pre-applied with
  – Upright heat bank cure

• Hand-held pneumatic dispense or robotic dispense with
  – Heat bank cure
  – UV trigger cure
  – Room temp cure

• Hand-held pneumatic dispense tip with
  – Heat clamp cure
  – UV trigger cure
  – Room temp cure
## Approach — Technology Options

<table>
<thead>
<tr>
<th>1K Liquid</th>
<th>1K Solid Epoxy</th>
<th>UV Triggered Epoxy</th>
<th>2K Epoxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-part epoxy designed for good balance of Tg and cure profiles</td>
<td>Patented epoxy that can solidify at room temp (can pre-apply on parts) then melt and cure with heat</td>
<td>Cure is triggered by exposure to UV; latency period allows for joint completion</td>
<td>2-part epoxy cures at room temperature</td>
</tr>
<tr>
<td>Pros: Would not require surface prep on Cu, Tg around 130°C</td>
<td>Pros: Good Tg, unique application method; RT stability of months in its solid form</td>
<td>Pros: Fast cure without heat; room temp stability; cure is triggered very rapidly</td>
<td>Pros: Room temp cure; room temp stable</td>
</tr>
<tr>
<td>Cons: Heat cure required; RT stability limited</td>
<td>Cons: Have to cure vertically (to get flow into joints)</td>
<td>Cons: OLS/Tg may not be achievable without secondary heat cure (?); may require surface prep. This concept not proven out yet</td>
<td>Cons: RT cure would have lower Tg (post cure may be needed); cure time vs. nozzle life; may require surface prep</td>
</tr>
</tbody>
</table>

**All formulations meet pressure requirements up to at least 180 °F**
Solid 1K Adhesives — Autobrazing Concept

Cost: $0.30 per joint
Quantitative Coverage — Neutron Imaging

- In situ curing
- Non-invasive

http://dx.doi.org/10.7717/peerj.453
Approach — Header & Subassembly Connections

- **Joint geometry optimization**
- **Adhesive application**
- **Header insertion**
- **Curing**

**Robotic dispensing arm with radiative heat bank cure**

**Robotic application system** detects pipe end and dispenses adhesive on male end (5 seconds/joint)  
Cost: $50,000

**1-part adhesive**  
Cost: $0.10 per joint

**Radiative Heat Bank:**
1. Position heat exchanger upright in radiative heat bank (2 min)  
2. Dwell time in heat bank (300°F) (20 min)  
3. Repeat for other side of heat exchanger, if needed  

Cost: $3000  
Energy Usage: ~29kW per heat exchanger cycle ($0.60/coil)
Surface Preparation Approach — Laser Structuring

Samples with different laser structuring conditions

2D surface profile with profilometry
Approach — Laser Structuring Enhancement

Method:
- Laser interference structure technique
- Shear strength measured by single lap joint test

(a) Laser raster with 6 mm/s (b) Laser raster with 12 mm/s

Failure mechanism: (a) adhesive failure, (b) mixed failure mechanism.

Results:
- Laser raster can leave a clean and structured surface
- Compared with traditional surface preparation methods, laser structure can enhance the bonding shear strength significantly
- Higher raster speed results in a higher shear strength

D: Traditional method  B: Laser raster with 6 mm/s  C: Laser raster with 12 mm/s
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

INSTRON 3345

Failure mechanism at the interface

Approach — System Testing and Demonstration

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

Vibration testing

Modified heat pump dryer system

Cycling
Stakeholder Engagement

- Approximately 40 HVAC-R-M companies contacted and with varying response and 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 (>18) 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 original equipment manufacturers 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
Progress and Remaining Work

3.5 year project

- Neutron imaging
- Coupon testing
- Surface preparation
- Adhesive formulation

Testing

- M24 – Meet 75% of joint strength requirements
- M33 – Meet full strength and leakage requirements
- Geometry optimization

Prototype testing

- M42 – Deliver tech-to-market plan and new product literature

Immediate future: Intensive joint testing, neutron imaging
Distant future: Prototype testing
Thank You

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REFERENCE SLIDES
Project Budget

Project Budget: DOE Total $1500K
Variances: Project delayed until 3/1/2017 due to contract negotiations
Cost to Date: $561K
Additional Funding: None

<table>
<thead>
<tr>
<th>Budget History</th>
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<tbody>
<tr>
<td>10/1/2016– FY 2018 (past)</td>
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<tr>
<td>DOE</td>
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<tr>
<td>$1,500K</td>
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# Project Plan and Schedule

## Project Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>FY2019</th>
<th>FY2020</th>
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</thead>
<tbody>
<tr>
<td>Project Beginning: 10/1/2016</td>
<td></td>
<td>Completed Work</td>
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<tr>
<td>Projected End: 3/1/2020</td>
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<td>Active Task (in progress work)</td>
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<tr>
<td>Q1 (Oct-Dec)</td>
<td></td>
<td>Milestone/Deliverable (Originally use)</td>
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<tr>
<td>Q2 (Jan-Mar)</td>
<td></td>
<td>Milestone/Deliverable (Actual) use</td>
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<tr>
<td>Q3 (Apr-Jun)</td>
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<tr>
<td>Q4 (Jul-Sep)</td>
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## Past Work

- HVAC&R manufacturers response
- Preliminary Cost Analysis
- Assessment of adhesive and surface combination

## Current/Future Work

- Go/No-Go Identification of joints that reach the joint strength requirement
- Preliminary cost analysis of current brazing process
- Complete T2M plan and product literature