Improved Braze Joint Quality Through use of Enhanced Surface Technologies

2017 Building Technologies Office Peer Review

\[ \gamma_{lv} \cos \theta = \gamma_{sv} - \gamma_{sl} \]
\[ \cos \theta^W = r \cos \theta \]

Brazephillic Features
Brazephobic Features
Project Summary

Timeline:
Start date: **10/3/2016**
Planned end date: 11/30/2018

Key Milestones
1. Milestone 1; 1/27/17 – Rationale for selection
2. Milestone 2; 2/21/17 – Potential landscape geometries

Budget:
**Total Project $ to Date:**
- DOE: $1534
- Cost Share: $313

**Total Project $:**
- DOE: $414,210
- Cost Share: $82,832

Key Partners:
University of Illinois at Champaign/Urbana

Project Outcome:
Maintenance of life cycle HVAC equipment efficiency by refrigerant retention through use of enhanced surface braze joints to reduce refrigerant leakage. Ultimate goal of reduction in refrigerant leaks by 25% and reduction in braze materials by 10%.
Purpose and Objectives

**Problem Statement:** One of the causes of reduced efficiency during the life cycle of commercial and residential HVAC products is loss of refrigerant charge, which is typically a result of leakage through commonly used braze joints.

**Target Market and Audience:** Commercial and residential HVAC industries will benefit from the technology development to reduce refrigerant leaks. This $50+B market’s energy consumption increase due to refrigerant leakage can be as high as 30 TBtu over a 10 year span for a single market segment.

**Impact of Project:**

**Project Output:** Life cycle improvements in HVAC&R equipment energy consumption through reduction in braze joint refrigerant leaks.

**Near-term outcomes:** Surface enhancement identification that enhances braze joint strength and thermal/pressure cycling capability. Investigation and validation of manufacturing processes.

**Intermediate outcomes:** Implementation of use in round tube plate fin coil manufacturing processes.

**Long-term outcomes:** Use of surface enhancements throughout commercial, residential HVAC, transport refrigeration and other industry brazing processes on all types of braze joints to minimize refrigerant leakage.
Approach: Engineered surface structures will be used to wick braze alloy and flux to brazing joint areas to create stronger and more robust braze joints. These surfaces for brazing would be braze alloy/flux phobic or philic to help direct the brazing materials.

Key Issues:
1. Surface topology identification through wicking capability and strength improvements
2. Cost of Surface Application
3. Ease of Manufacturability

Distinctive Characteristics: Attacks issues within a mature manufacturing process methodology through use of new surface topologies
Approach

Use of brazophilic and brazephobic surface features to move braze alloy to areas needed to improve braze joint strength and reliability

- Improve braze joint hydrostatic burst strength
- Improve braze joint thermal/pressure cycling capability
- Meet or exceed braze penetration internal requirements
- Reduce internal U-bend leak rates while maintaining or lessening cost per U-bend joint
Progress and Accomplishments

Accomplishments:
- Braze training completed for UIUC researchers to understand existing process
- Braze materials and surface material determination
Progress and Accomplishments

Accomplishments:

- Experimental test rig determined and designed to observe the interaction between the braze material and modified copper surface. Test rig will help with repeatability of measurements with regards to wicking and capillary action based on surface enhancement.
Experimental Test Rig

- Vertical track for camera
- Camera for visualizing flow characteristics on modified copper surfaces
- Braze material
- Multi-axis stage
- Precision micrometer actuators
  - Sensitivity: 0.1 microns
  - Vertical travel: 8 mm

- Heat shielding around the setup to prevent any accidental damage to other equipment

- Mounts
- Solid aluminum breadboard

- Torch with twin tips

- Infrared camera to map the heat distribution and flow characteristics of the braze alloy

- IR Camera
- Heat shielding

- Fire Extinguisher
- Propane tank with regulator and flashback arrester
- Oxygen tank with regulator and flashback arrester

- 2 ft
Top View of Experimental Test Rig

- Heat shielding
- Bread board
- Additional camera mounting points
- Vertical track for camera
- Multi-axis stage
- Torch
- Thermal or high speed camera
Observation Techniques

• The interaction between the braze material and the modified copper surface will be explored using various observation techniques.

• Top and side views of a single plate with heat source on the bottom.
  – Characterize viscous flow over a porous media.
  – Measure propagation speed.
  – Measure spreading parameters with respect to time.
  – Thermal camera can monitor temperature profiles of the flow.
Observation Techniques

• Front view of a single plate with heat source on the bottom.
  – Measure spreading parameters with respect to time.
  – Thermal camera can monitor temperature profiles of the flow.

• Front and side views of sandwiched plates with heat source on top and bottom.
  – Observe and quantify capillarity effect.
  – Observe flow spreading and propagation.
  – Introduce combination of brazophillic and brazephobic surfaces.
Progress and Accomplishments

Accomplishments:

• Initiation of landscaping of surface structures and creation techniques
  – Examining different techniques for creation of surfaces and surface topology itself
    • Creation of surfaces through mechanical techniques
    • Non-mechanical surface creation

• Initiation of modeling of liquid braze alloy propagation
  – Models to predict liquid propagation rates in capillary tubes that balances capillary pressure with viscous resistance.
  – Tools for prediction of capillary pressure.
  – Find the viscous resistance of pillar arrays by idealizing them as infinitely long cylinders
  – Semianalytical model to predict liquid propagation rates based on the diameter, height and period of the micropillars
Progress and Accomplishments

Market Impact:
• Too early in project at this stage (Budget Period 1) to quantify impact on products
• Cost analysis will be conducted in Budget Period 2

Awards/Recognition:
• Prof. Nenad Miljkovic – ONR 2017 Young Investigator Award Recipient

Lessons Learned:
• Removal of manual brazing inconsistencies key to achieving valid selection of surface enhancement
• Business development agreements need to hammered out very early in the application process to allow for immediate commencement of work
**Project Integration**

Project Integration: Trane and UIUC teams are meeting biweekly to ensure that progress is well understood, communication flows and that potential solutions are viable from a manufacturing process perspective.

**Partners, Subcontractors, and Collaborators:**

Partners, Subcontractors, and Collaborators: UIUC (Prof. Nenad Miljkovic) is the primary subcontractor for identification of enhanced surface topologies.

**Communications:**

Communications: None – Project initiated fall 2016.
Next Steps and Future Plans:

- Determination of surface geometry enhancements to compare
- Surface Geometry Candidate Comparison – April to December 2017
  - Comparison of surface geometries in flat plate braze test apparatus
  - Comparison of surface geometries in round tube braze test
  - Initial manufacturing cost analysis
  - Selection of surface geometry for manufacturing maturation
- Surface Geometry Maturation – January 2018 to November 2018
  - Soft tooling determination and acquisition
  - Manufacturing of large sample size for testing and analysis
  - Reliability testing
  - Manufacturing cost analysis
Project Budget: Started with proposal budget and slowly ramping up with subaward agreement

Variances: Spend to ramp up in next quarter with subcontractor expenses

Cost to Date: $1,534

Additional Funding: None

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<thead>
<tr>
<th>Budget History</th>
<th>FY 2016 – 10/1/16 (past)</th>
<th>FY 2017 (current)</th>
<th>FY 2018 – 11/30/18 (planned)</th>
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### Project Plan and Schedule

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<tr>
<th>Task Name</th>
<th>Start</th>
<th>Finish</th>
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<tbody>
<tr>
<td>A- Completion of IP Management Plan</td>
<td>Thu 9/1/16</td>
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<td>1A-IPMP signed by representative parties and approved by DOE</td>
<td>Fri 9/2/16</td>
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<tr>
<td>B1-Define SoA brazing processes</td>
<td>Mon 9/5/16</td>
<td>Fri 11/16/16</td>
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<td>Milestone B1- SoA brazing process</td>
<td>Thu 12/1/16</td>
<td>Tue 2/21/17</td>
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<td>B2- Training of Members</td>
<td>Tue 11/1/16</td>
<td>Fri 12/2/16</td>
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<td>B3- Background Determination of alloys and fluxes</td>
<td>Mon 12/5/16</td>
<td>Thu 12/8/16</td>
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<td>B4- Landscape Potential Geometries</td>
<td>Wed 2/1/17</td>
<td>Tue 2/28/17</td>
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<td>C4- Dissemination of potential landscape geometries to DOE</td>
<td>Wed 2/1/17</td>
<td>Wed 3/1/17</td>
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<td>C- Selection process for microstructure geometry determination</td>
<td>Mon 5/1/17</td>
<td>Thu 12/7/17</td>
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<td>C1- Create different surface geometries thru sanding and</td>
<td>Mon 5/1/17</td>
<td>Fri 5/19/17</td>
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<td>C2- Brazing tube geometries with different geometries</td>
<td>Mon 5/22/17</td>
<td>Wed 5/31/17</td>
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<td>C2- Review of generated surfaces</td>
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<td>Wed 5/31/17</td>
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<td>C3- Section and analyze braze joints</td>
<td>Thu 6/1/17</td>
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<td>C4- Burst test braze joints</td>
<td>Thu 8/1/17</td>
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<td>C5- Brazing samples autobraser</td>
<td>Wed 7/5/17</td>
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<td>C6- Iterate design geometries for improvements</td>
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<td>C9- Section and analyze joints</td>
<td>Sat 10/21/17</td>
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<td>C12- Initial Manufacturing Cost Study</td>
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