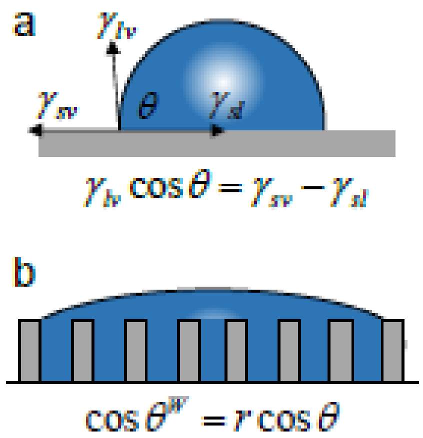
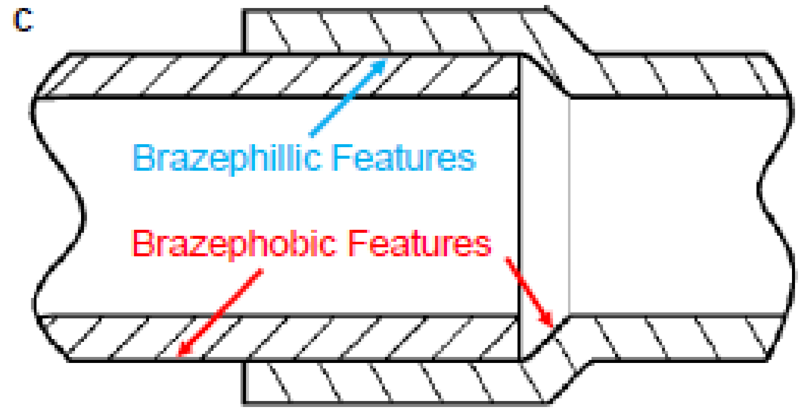
Improved Braze Joint Quality Through use of Enhanced Surface Technologies





Trane US Inc., a company of Ingersoll Rand
Brian Westfall – VP Advanced Manufacturing Engineering
803.714.2950

Project Summary

Timeline:

Start date: **10/3/2016**

Planned end date: **3/30/2019**

Key Milestones

1. Milestone 1; 1/27/17 – Rationale for selection
2. Milestone 2; 2/21/17 – Potential landscape geometries
3. Milestone 3; 5/15/18 - Candidate for maturation and manufacturability assessment
4. Milestone 4; 3/30/19Manufacturing and proof of concept verification

Budget:

Total Project $ to Date:

- DOE: $136,813
- Cost Share: $35,062

Total Project $:

- DOE: $327,820
- Cost Share: $85,318

Key Partners:

University of Illinois at Champaign/Urbana

ILLINOIS

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%.

Team

Nenad Miljkovic – UIUC lead investigator

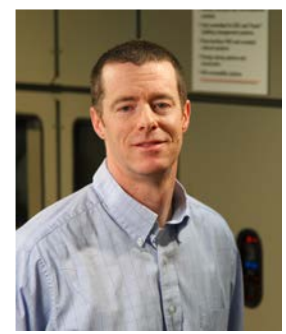
Kalyan Boyina – UIUC primary grad student researcher

TRANE

Brian Westfall – PI - VP Advanced Manufacturing Engineering

Melanie Rowe – AME braze engineer

Laura Murry – Materials Engineer



Ron Cosby – NA Commercial HVAC Technology Leader

Challenge

Problem Statement: One of the causes of reduced efficiency during the life cycle of commercial and residential HVAC products is loss of refrigerant charge

- Systems leave manufacturing facilities having been proofed and leak checked
- Over time charge is lost through tiny joint leakage due to vibration, structure movement, etc.
- Loss of charge from an optimized system can result in dramatic efficiency reductions dependent upon the type of system and components used

Target Market and Audience: Commercial and residential HVAC industries and their customers 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.

- Reduced customer life cycle energy consumption and cost
- Reduced direct and indirect GHG emissions

Approach

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.

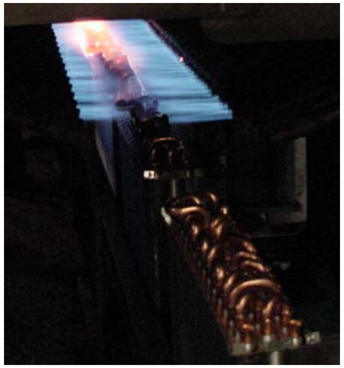
Key Issues:

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

Impact

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

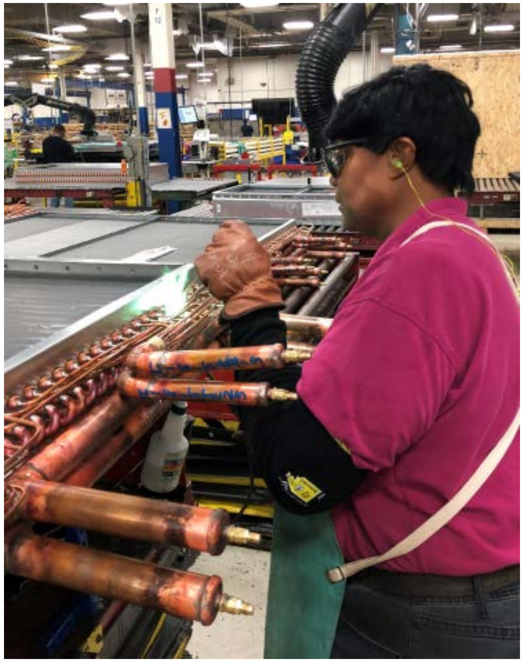


Near-term outcomes: Surface enhancement identification that enhances braze joint strength and ability of components to withstand thermal/pressure cycling capability. Investigation and validation of manufacturing processes.

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

Impact



Technology Differentiation:

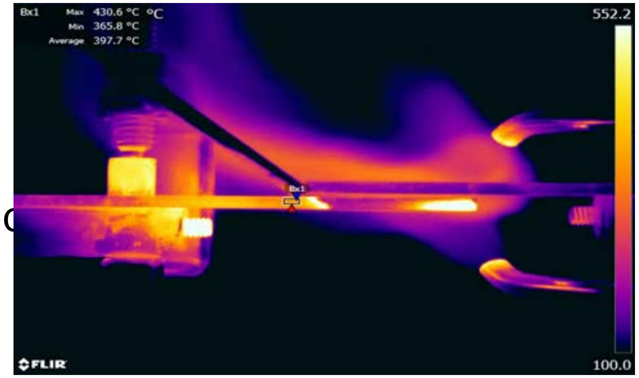
- Project attacks a very mature manufacturing process to improve robustness of braze joints to garner energy savings
  - Reduce energy consumption through small changes on billions of U.S. braze joints to garner life cycle energy consumption improvements
  - 10-50 TBtu of savings with improvements in annual refrigerant loss reduction

- Final year of project examines manufacturability to ensure that additional manufacturing tasks do not negatively impact manufacturing and/or design cost
  - Cost of surface enhancement
  - Brazing takt time changes
  - Braze alloy cost improvements

Progress

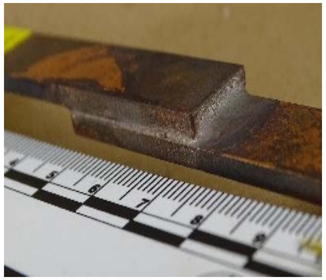
Overview of Accomplishments:

- Landscaping of existing technologies and information on microstructures
  - Manufacturing techniques
  - Modeling of potential braze flow
- Initial microstructure surface assessment nearing completion (midpoint of project)
  - Assessments completed on flat plate geometries
  - Brazing conducted on representative tube braze joints by 4/1/18



Schedule:

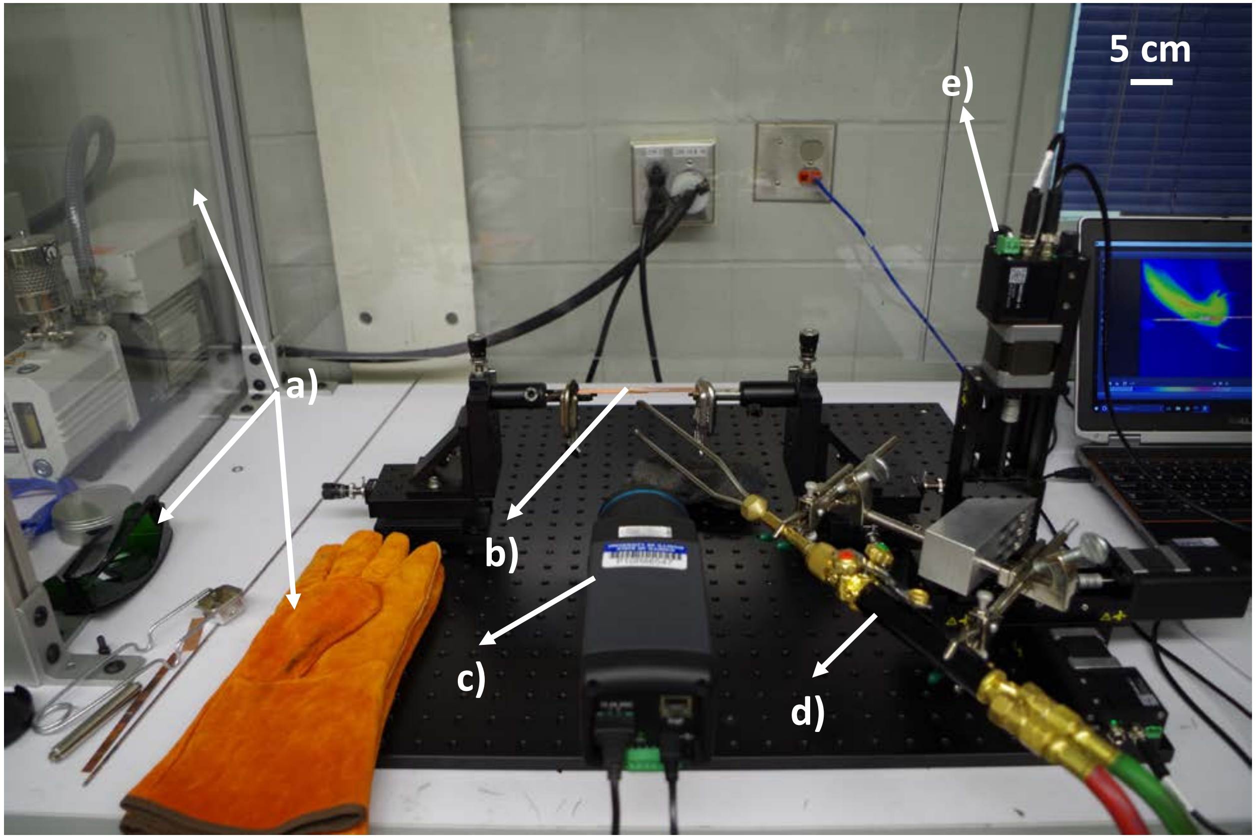
- Delays occurred during the first year due to consistency issues with experimental test rig and flat plate joint geometries – required some rework
  - Brazing process consistency for surface geometry assessment
  - Lap joint validity for strength assessment
- End of project now moved out six months to 3/30/19

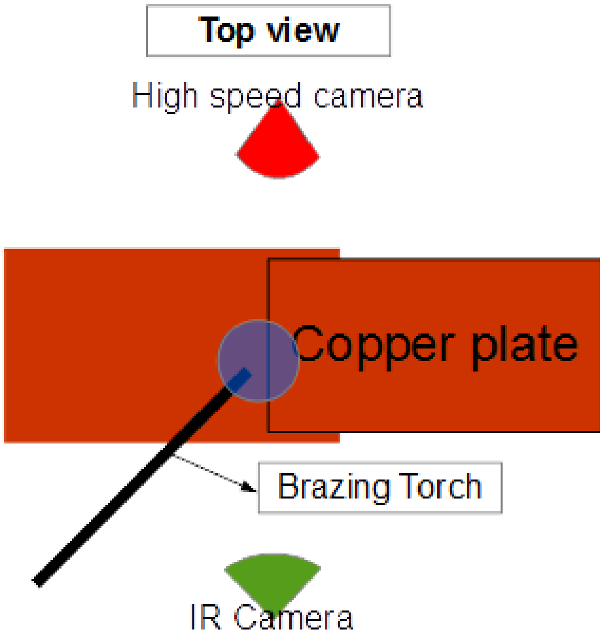


Progress

Accomplishments:

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

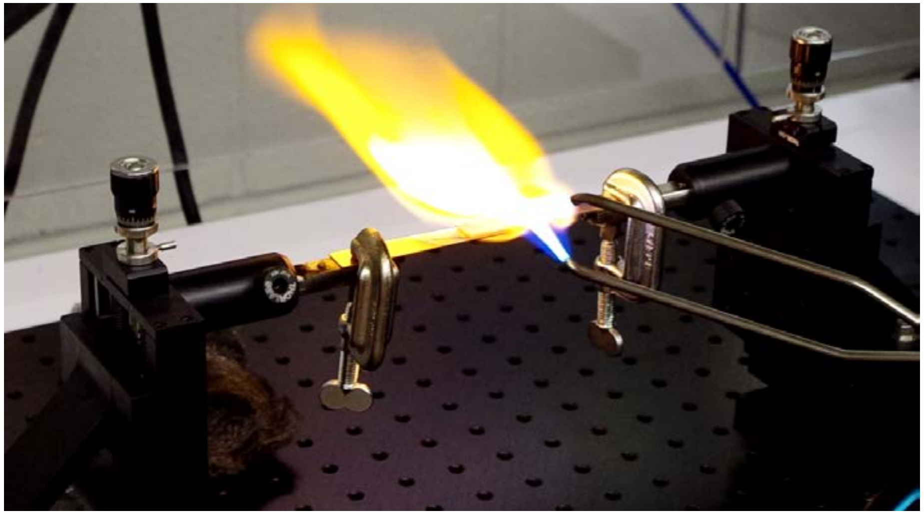




a) Protective equipment (flame barrier, welding goggles, and welding gloves) b) Overlapping samples, c) Infrared Camera, d) Brazing torch attached to the linear actuator setup, and e) 3-axis programmable linear actuator setup

Progress

- The interaction between the braze material and the modified copper surface was explored using various observation techniques including high speed camera and thermal imaging
- Top and side views of a single plate with heat source on the bottom.
  - Characterized viscous flow over a porous media.
  - Measured propagation speed.
  - Measured spreading parameters with respect to time.
  - Thermal camera monitored temperature profiles of the flow
  - Determined strength characteristics with different surfaces



Progress

- Have moved in the last 1.5 months from flat plate braze samples to tube braze samples with different surface enhancements after seeing ability to change brazing characteristics
  - Manually brazed joints

Current Work

- Conducting burst strength tests to determine initial braze joint strength assessment for enhanced vs. unenhanced surfaces
  - Comparison of different enhanced surfaces against each other on realistic HVAC braze joints
- Sectioning of tube braze joints to determine if braze voids and porosity issues exist

Stakeholder Engagement

Downstream implementation:

- Should the technology be technically viable and cost justified for manufacturing, the PI and Trane team will move to implement
- Initiate with copper round tube plate fin coil manufacturing locations
  - Multiple facilities for coil manufacturing for HVAC equipment (unitary rooftops, WSHP, chillers, etc.)
- Assuming acceptable implementation and improved lifecycle benefits would move to pursue in adjacent areas
  - Aluminum round tube plate fin coil manufacturing locations (residential HVAC)
  - Larger interconnecting piping braze joints (unitary rooftops, WSHP, chillers, transport refrigeration)
  - Dissimilar metal braze joints (unitary rooftops, chillers, transport refrigeration, residential HVAC)
- Determine applicability for cost savings and/or strength improvements on non-refrigerant bearing braze joints

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Remaining Project Work

Work remaining:

- Pending success of brazed tube joint burst tests and acceptable braze section analysis, the team will determine the optimal microstructure to mature further within a manufacturing setting – 2Q18

- Larger scale braze joint creation and brazing – 4Q18
  - Utilization in a near manufacturing based representation
  - Actual brazers – no automation
  - Larger number of joints
  - Strength and sectioning analyses
- Initial assessment of manufacturability – 4Q18
- Reliability testing analysis versus current brazing techniques – 1Q19

- Cost analysis of technology – 2Q19
- Commercialization plan – 2Q19

Thank You

Trane and University of Illinois
Brian Westfall – VP Advanced Manufacturing Engineering
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REFERENCE SLIDES

Project Budget

Project Budget: BP 1- $200,975 BP 2- $212,163 – Total of $413,138
Variances: Budget Period 1 expense budget $200,975- actual $171,876- moved $29,099 to BP 2.
Cost to Date: 41.6% ($171,876)
Additional Funding: None

	Federal	Cost Share	Total Costs
Budget Period 1	$136,813	$35,063	$171,876
Budget Period 2	$191,007	$50,255	$241,262
Budget Period 3	$0	$0	$0
Total	$327,820	$85,318	$413,138

Budget History

10/1/2016 – FY 2017 (past)		FY 2018 (current)		FY 2019 – 12/31/18 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
160,035	40,940	167,785	44,378	$0	$0

Project Plan and Schedule

Project Schedule		
Project Start: 10/3/2016		Completed Work
Projected End: 3/30/2019		Active Task (in progress work)
		Milestone/Deliverable (Originally Planned) use for missed
		Milestone/Deliverable (Actual) use when met on time

	FY2016				FY2017				FY2018			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Rationale for selection												
Q2 Milestone: Review of landscaping candidates												
Q2 Milestone: Review of generated surfaces and initial manually brazed joint analysis												
Q3 Milestone: Initial assessment of braze joint improvements												
Q4-Q7 Milestone: Assessment of microstructure enhancement candidates for further maturation												
Current/Future Work												
Q9 Milestone: Initial manufacturability assessment												
Q10 Milestone: Reliability testing												
Q10 Milestone: Manufacturing technique for brazing system												

Project Plan and Schedule

Schedule slips:

- Assessment of microstructure enhancement candidates came with iteration upon the experimental test rig configuration for brazing, iteration of braze samples because of elongated braze joints and assessment

Critical Go/No-Go decision point and Future Work:

- Upcoming assessment with actual tube geometries will be a critical juncture for the project – April to May 2018
  - Determination of burst strength enhancement
  - Determination of braze alloy use reduction
  - Above two provide input for manufacturability assessment and geometry determination for maturation of manufacturing techniques
  - Should assessment indicate further iteration is required then current schedule will need to be revamped
- Remainder of 2018 and 2019
  - Work on manufacturability – soft tooling for enhancement creation
  - Larger scale sample manufacturing by Trane