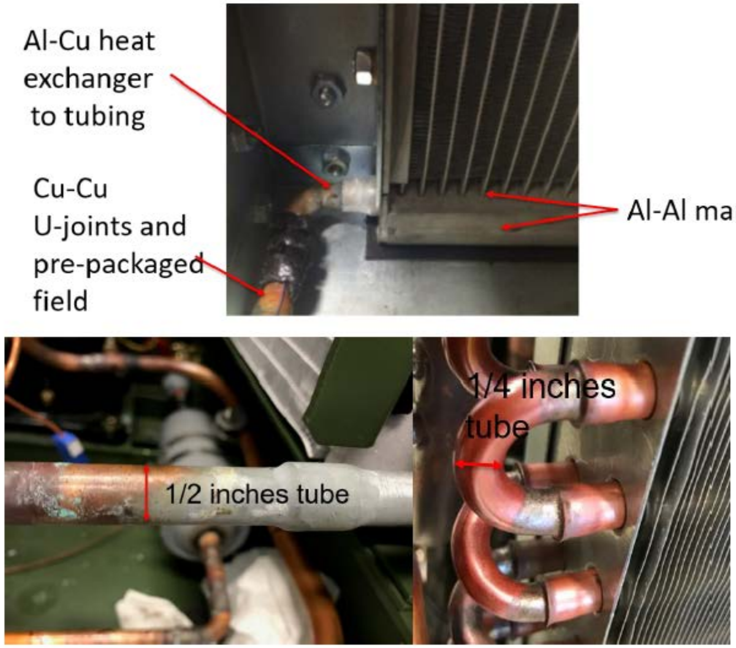
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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. 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 Science. Applied to Life.™

Herrick Laboratories PURDUE UNIVERSITY™

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

OAK RIDGE National Laboratory

3M Science. Applied to Life.™

Patrick Geoghegan, PhD.
Principal Investigator

Adrian Sabau, PhD.
Materials Science R&D Staff

Shari Loushin
Lead Application Engineering Specialist

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

Matthew Kryger, PhD.
Research Polymer Scientist

World leaders in adhesives

Herrick Laboratories PURDUE UNIVERSITY™

Renowned graduate program

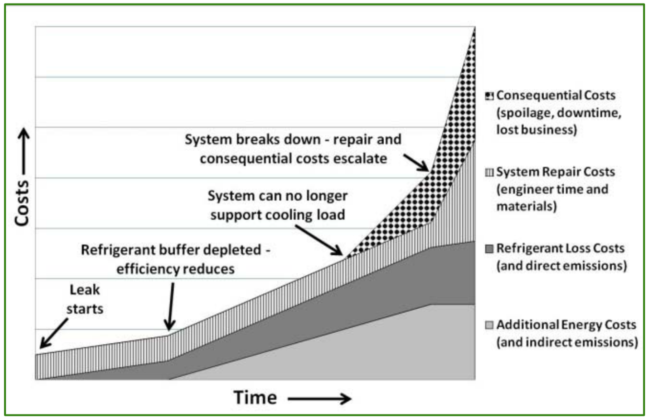
Eckhard A. Groll
Reilly Professor of Mechanical Engineering & Associate Dean of Undergraduate and Graduate Education, College of Engineering

Haotian Liu
Ph.D. Student

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

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



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

How Much Do Common Air Conditioner Repairs Cost?

Here are some common types of air conditioner problems and their average associated costs:

- Refrigerant leak detection and repair: **$225-$1600**
- AC refrigerant recharge: **$160-$400**
- Circuit board replacement: **$120-$600**
- Replace fuses, circuit breakers or relays: **$15-$300**
- Thermostat replacement: **$60-$250**
- A/C compressor repair hard start kit: **$100-$250**
- Capacitor or contactor replacement: **$90-$400**
- Home air compressor replacement: **$1350-$1800**, depending on size and type
- Evaporator coil replacement: **$650-$1200**
- Condensing unit fan motor replacement: **$100-$300**
- Condensate pump replacement: **$90-$250**

A troubleshooting service call can vary from **$75 to $180**, depending largely on your geographical location and the time of year in which the call occurs. The time of HVAC professionals is at a premium during the hot summer months.

www.homeadvisor.com

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

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

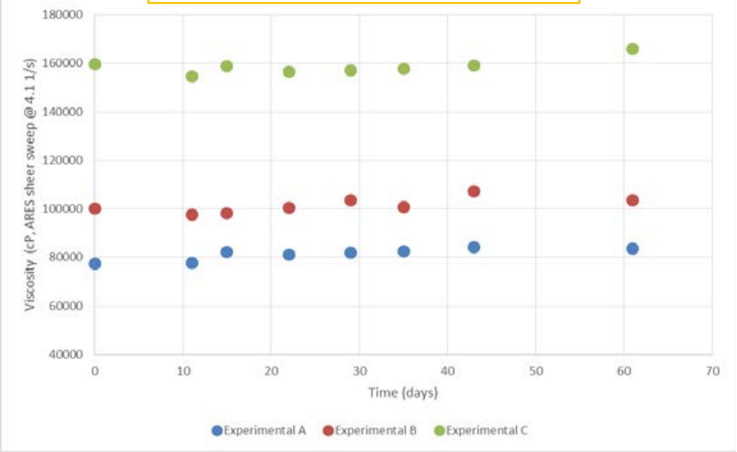
Adhesive Approach – Improved 1K epoxy

Materials in development

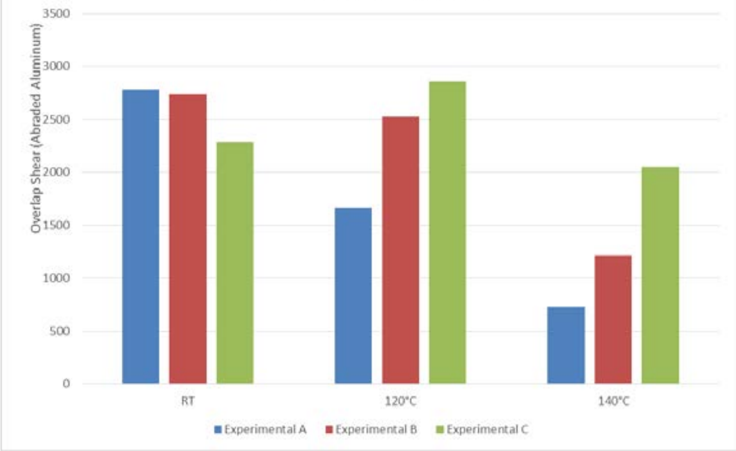
- Minimal increase in viscosity over time
- Good high temperature performance
- Improved thermal properties compared to past 2k brazing materials
- Fatigue testing in progress

Formulation	Tg (DSC)
Experimental A	121 °C
Experimental B	131 °C
Experimental C	141 °C

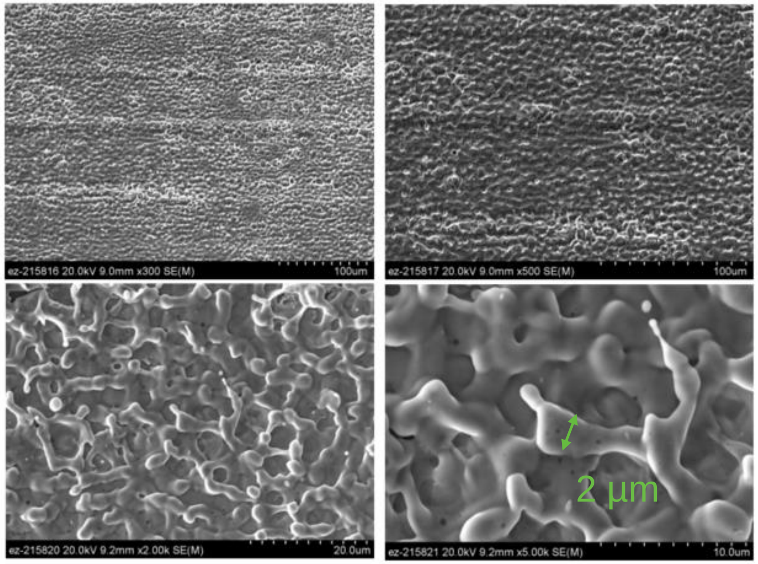
Viscosity Vs. Time

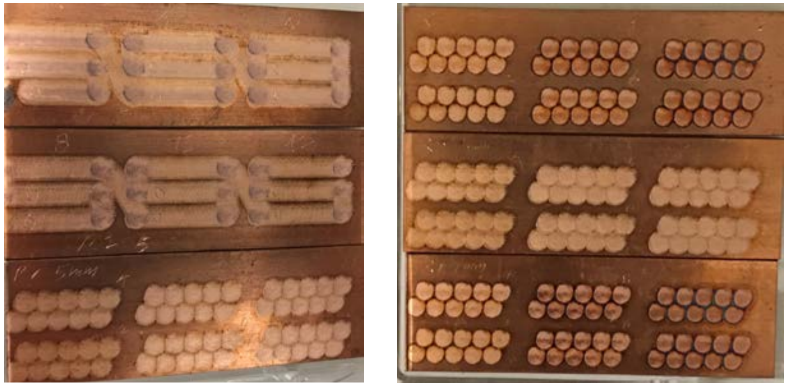


OLS Temperature Comparison

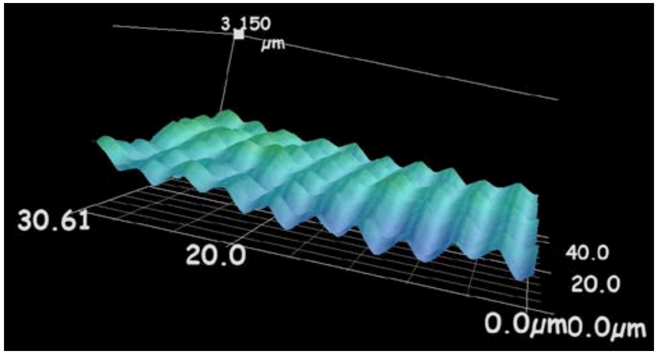


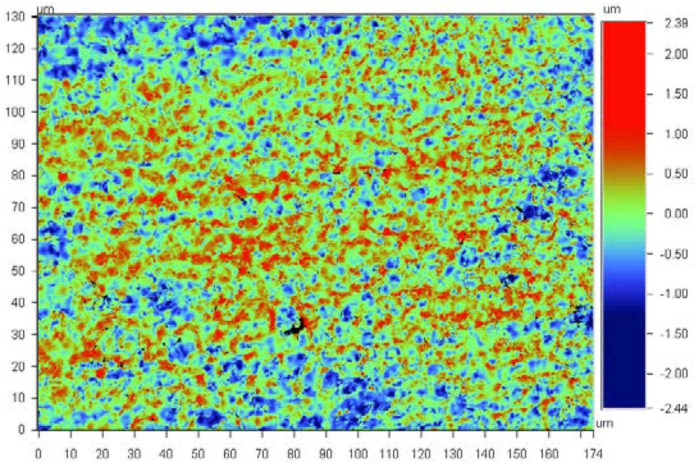
Surface Preparation Approach – Laser structuring





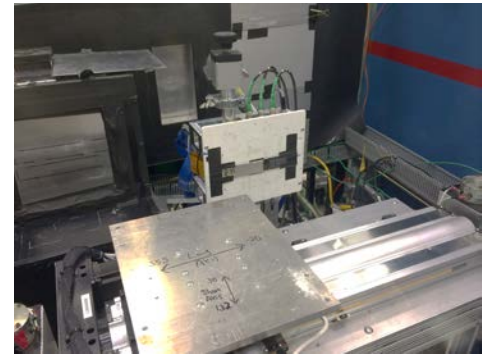
Samples with different laser structing conditions

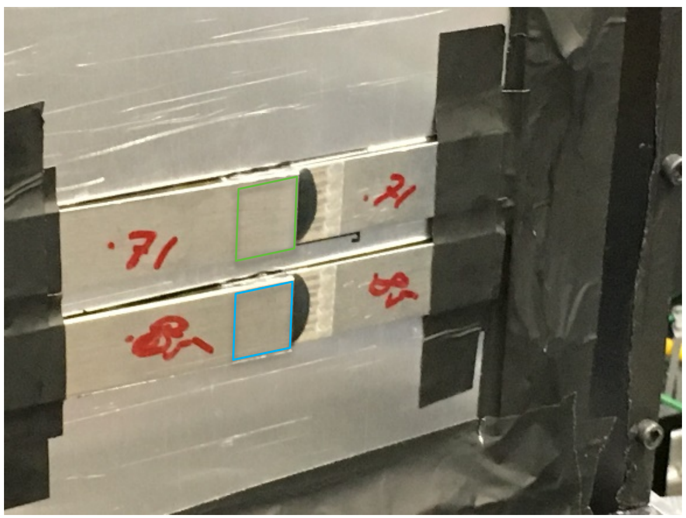


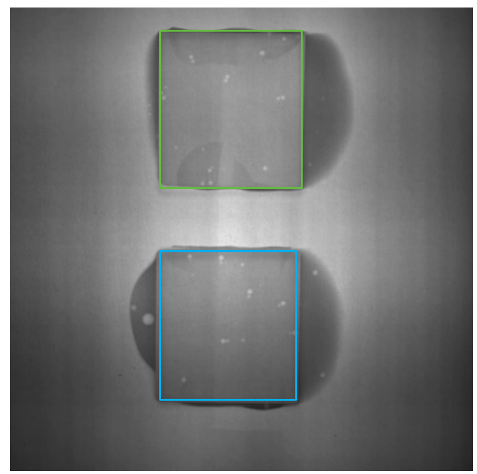


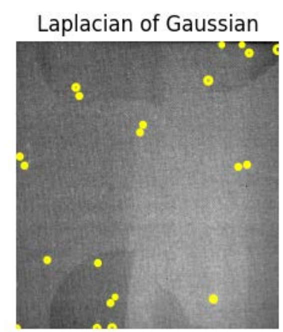
2D surface profile with profilometry

Quantitative Coverage – Neutron Imaging









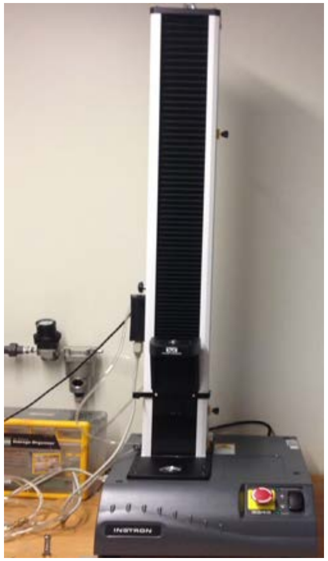
scikit-image

scikit-image.org
http://dx.doi.org/10.7717/peerj.453

In-situ curing

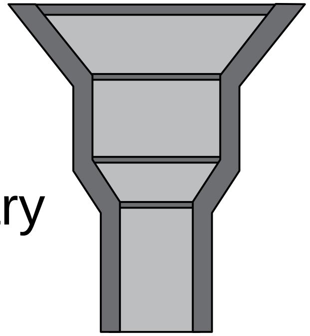
Adhesive Characterization driving ABAQUS modeling

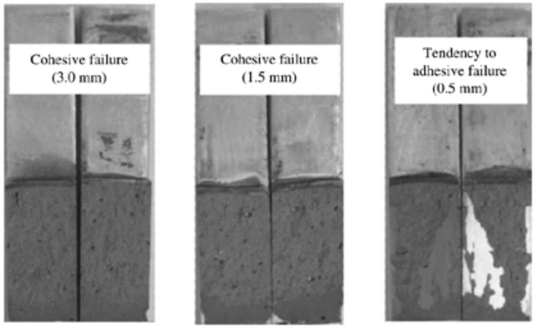
- Epoxy adhesive with cohesive failure:
  - Fracture toughness: Double cantilever beam (DCB) test; End-notched flexure (ENF) test
  - DCB samples will be prepared similarly as for previous studies at Purdue University
  - Elastic/shear modulus: tensile/shear test



INSTRON 3345

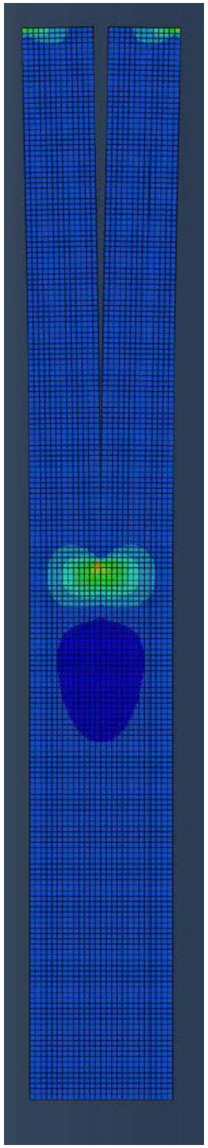
Optimized flare geometry





Failure mechanism at the interface

Jibin Han & Thomas Siegmund (2012) Cohesive Zone Model Characterization of the Adhesive Hysol EA-9394, Journal of Adhesion Science and Technology, 26:8-9, 1033-1052



Road Map: Fatigue prediction of tube-in-tube joint

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

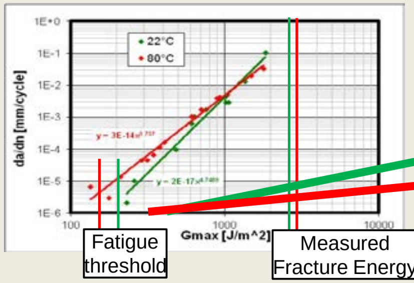
2) Obtained and measured tensile & CTE properties of adhesive & tubes

3) Created & ran FEA model of joint:

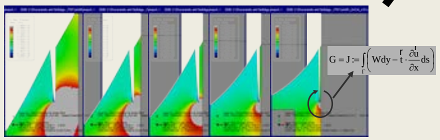
Hoop stress at -55C ~ 85% of fail
-Unaffected by joint design
Radial stress at -55C ~15% of fail
-Affected by bond & tube thickness

Ambiguous modeling results

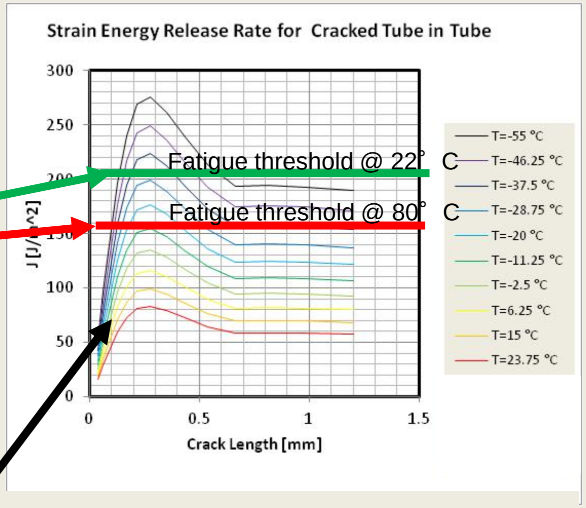
4) Measured fatigue properties
(Measurements of DP460NS by CNRC Chicoutimi, funded by 3M)



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



6) Combined measurement & model results to make assessment:

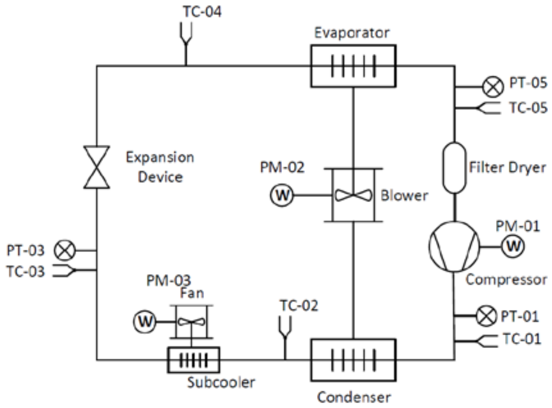


Analysis Conclusion:
- Stress driven energy release rate below fatigue threshold for comparable temperatures.
- Possible initiation of small crack at -55C end but not enough energy to drive propagation
- Joint should last. Some design refinement would improve safety factor.

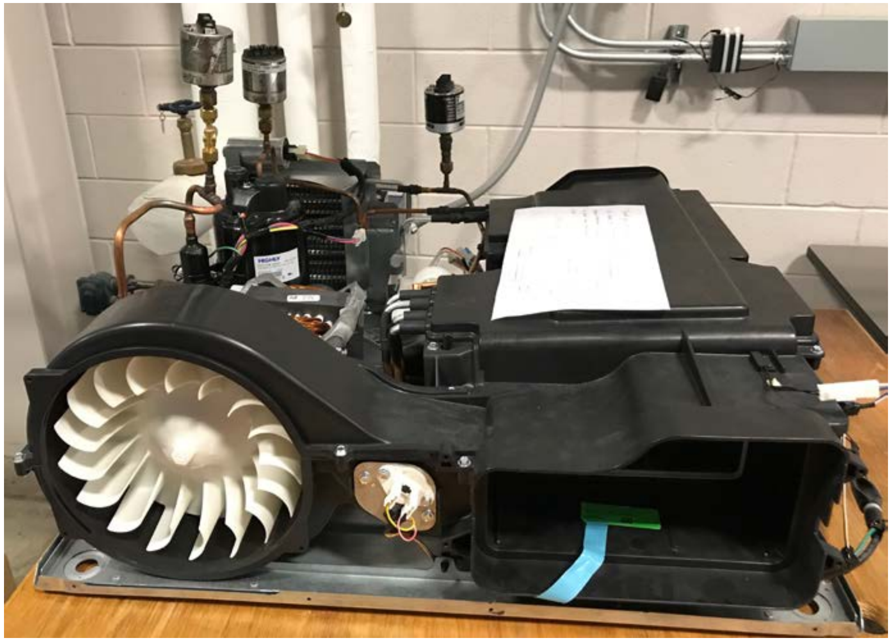
Postlude: Joint cycled >1000 cycles possibly more with no failures.

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



Modified heat pump dryer 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**

Braze suppliers	Aluminum Microchannel heat exchanger manufacturers
Flaring equipment manufacturers	AC Equipment Manufacturers
Potable water/ chillers	Brazed plate heat exchanger manufacturers

- **ASHRAE RP-1808 "Servicing and Installing Equipment using Flammable Refrigerants: Assessment of Field-made Mechanical Joints"**
- **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

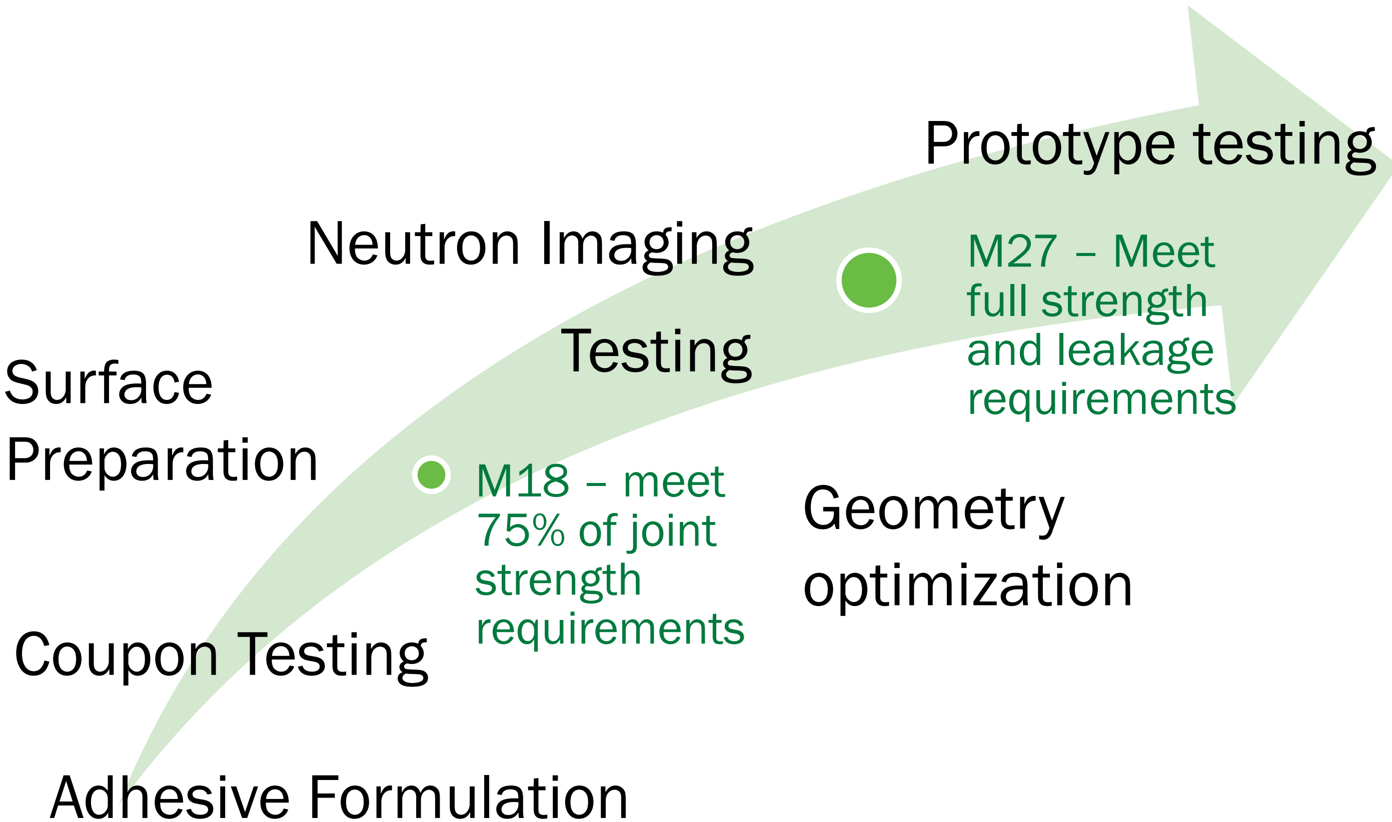
- Aluminum microchannel heat exchanger to copper tube connection
- Copper to copper U bends
- New heat exchanger concepts, particularly for aluminum heat exchangers
- Refrigerant Compatibility

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



M36 - Deliver Tech to Market Plan and New Product literature

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: $450K
Additional Funding: None

Budget History					
10/1/2016– FY 2017 (past)		FY 2018 (current)		FY 2019 – 3/1/2020 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$250K		$500K		$750K	

Project Plan and Schedule

Project Schedule												
Project Beginning: 10/1/2016		Completed Work										
Projected End: 3/1/2020		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned) use for missed										
		Milestone/Deliverable (Actual) use when met on time										
	FY2017				FY2018				FY2019			
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: DMP and IPMP												
Q2 Milestone: Surface Preparation												
Q3 Milestone: Joint strength Assessment												
Q4 Milestone: Gauge HVAC&R Interest												
Current/Future Work												
Q1 Milestone: Preliminary Cost Analysis of current brazing processes												
Q2 Go/No Go: Assessment of adhesive and surface combination												
Q3 Milestone: Joint Coverage through Neutron Imaging												