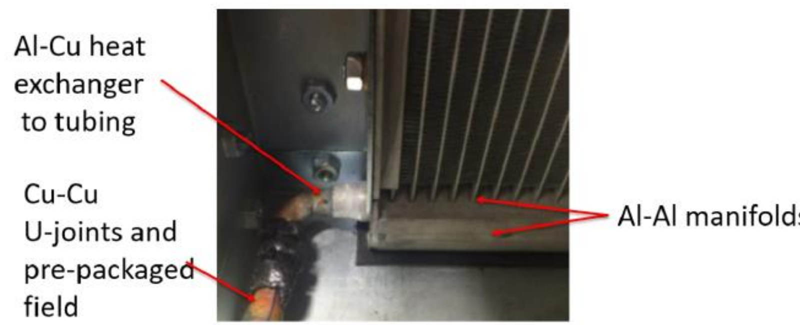
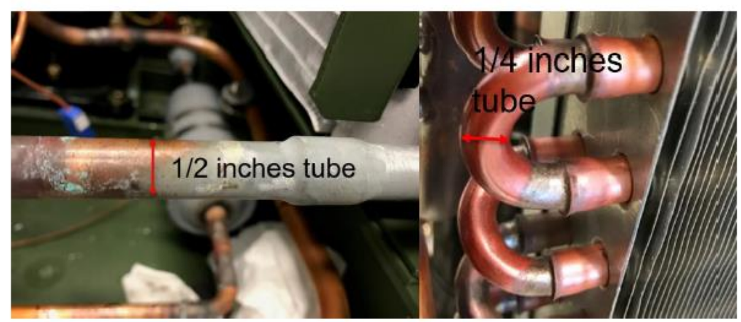
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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. 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: $*

Total Project $:

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

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

Key Partners:

Oak Ridge National Laboratory

Herrick Laboratories Purdue University

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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

<u>Patrick Geoghegan, PhD</u>
Principal Investigator

<u>Adrian Sabau, PhD</u>
Materials Science R&D Staff

<u>Shari Loushin</u>
Lead Application Engineering Specialist

<u>Matthew Kryger, PhD</u>
Research Polymer Scientist

3M: World leaders in adhesives

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

Purdue University: Renowned graduate program

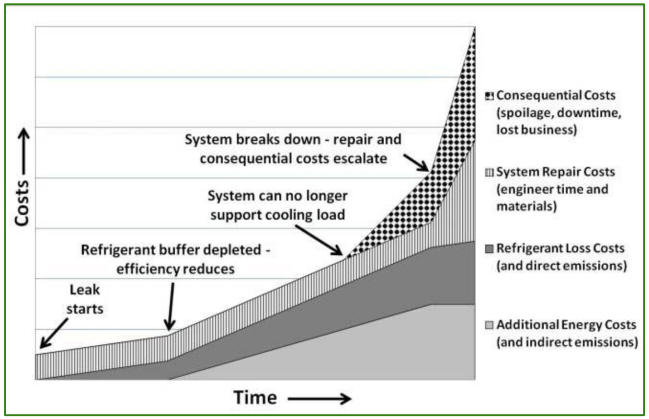
<u>Eckhard A. Groll</u>
Reilly Professor of Mechanical Engineering & Associate Dean of Undergraduate and Graduate Education, College of Engineering

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

<u>Haotian Liu</u>
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



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

Braze Replacement Adhesive — Concepts

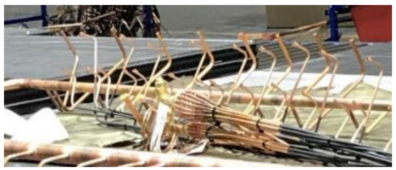
Subassembly manufacturing

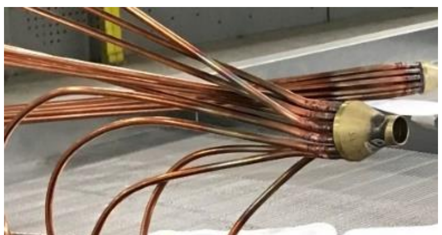
Heat exchanger (tube & fin) manufacturing

U-bend attachment

Header attachment

Unit assembly connections





Braze Replacement Adhesive Concepts

- 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

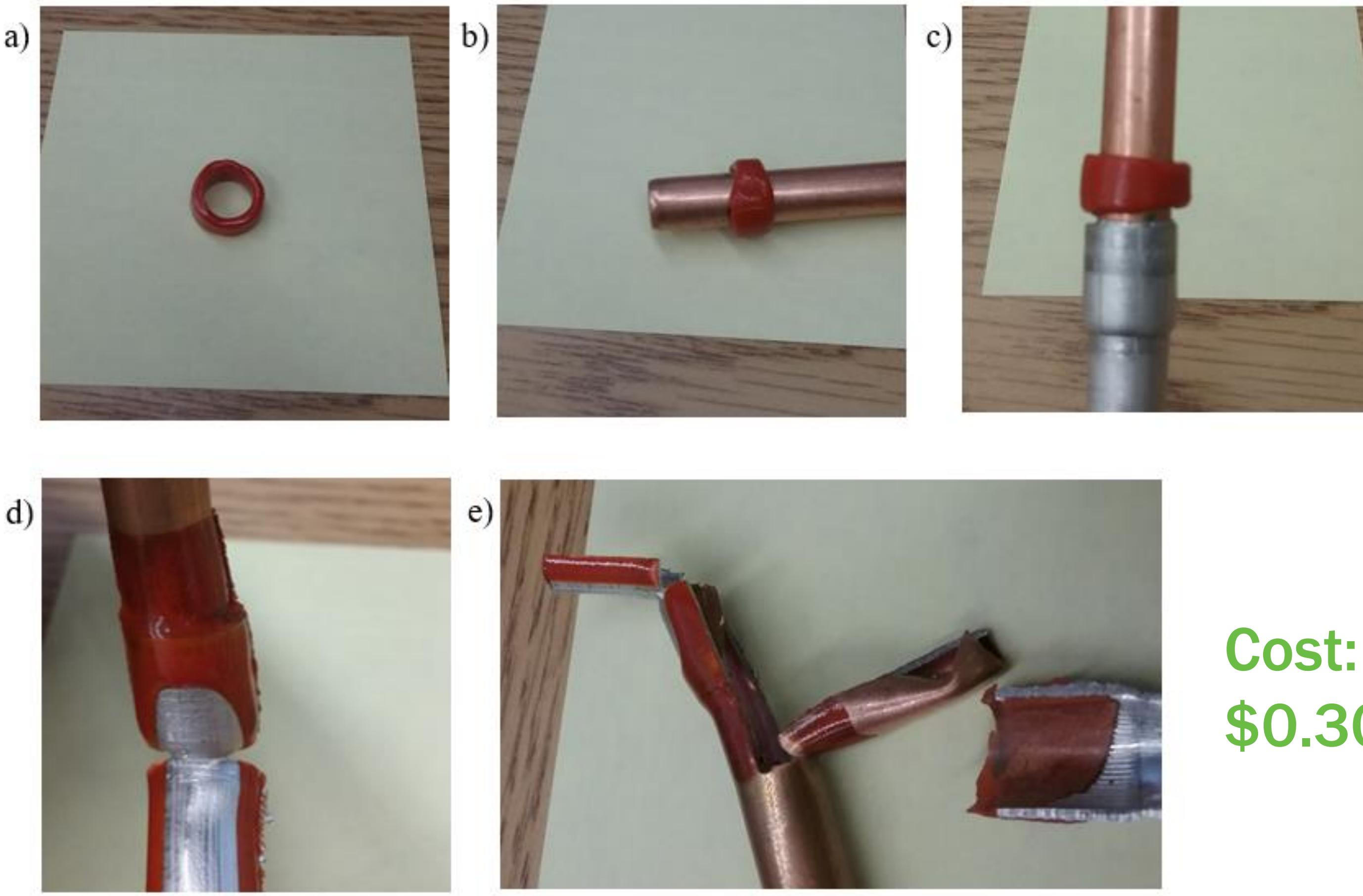
Approach — Technology Options

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

All formulations meet pressure requirements up to at least 180°F

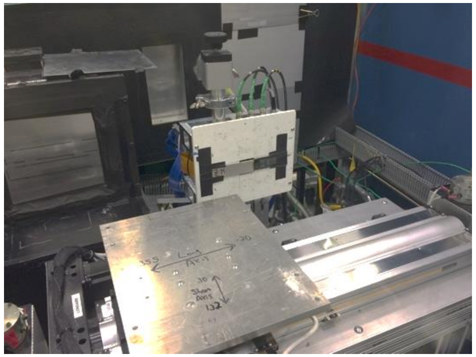
Solid 1K Adhesives — Autobrazing Concept

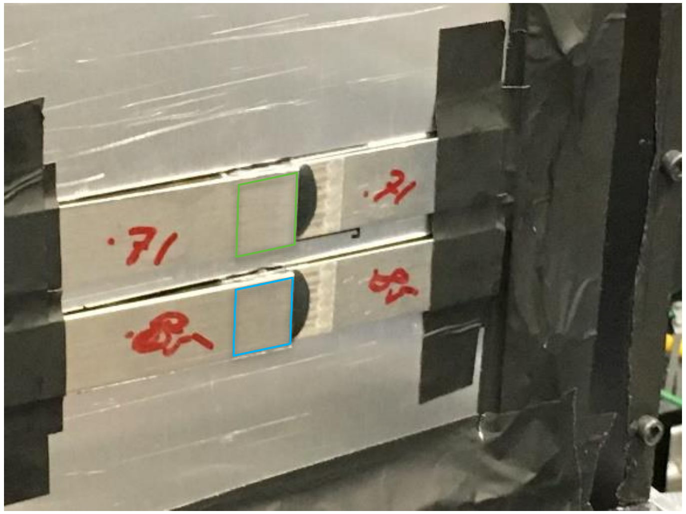
MJK-177

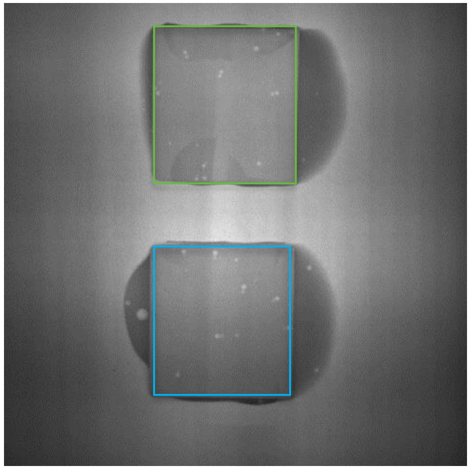


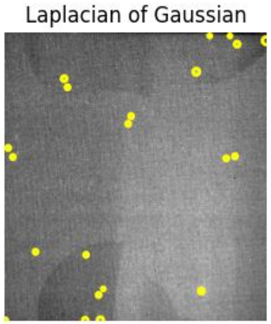
Cost:
$0.30 per joint

Quantitative Coverage — Neutron Imaging









scikit-image
image processing in python

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

- In situ curing
- Non-invasive

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

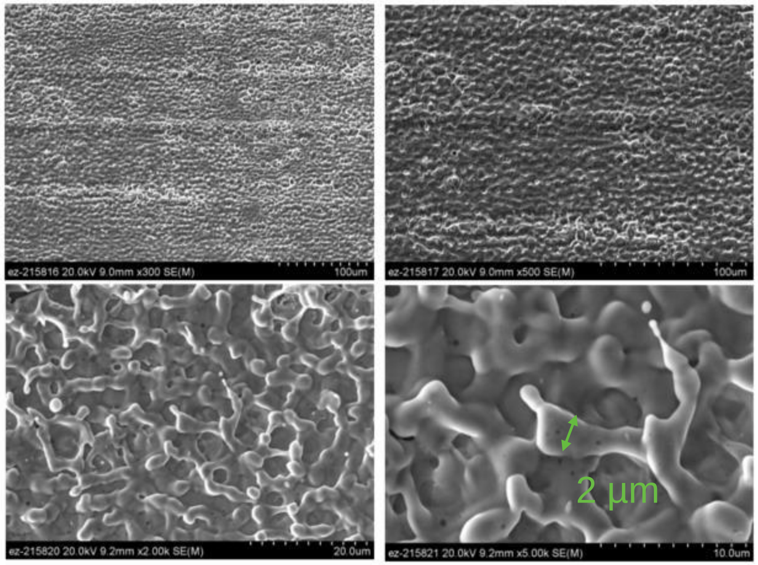
1-part adhesive
Cost: $0.10 per joint

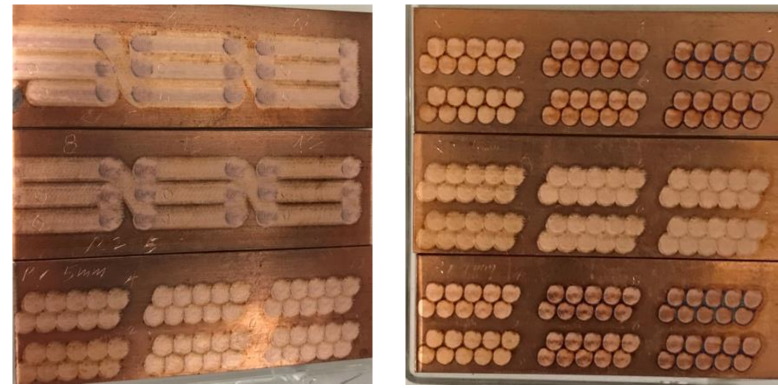
Radiative Heat Bank:

1. Position heat exchanger upright in radiative heat bank (2 min)
2. Dwell time in heat bank (300^0F) (20 min)
3. Repeat for other side of heat exchanger, if needed

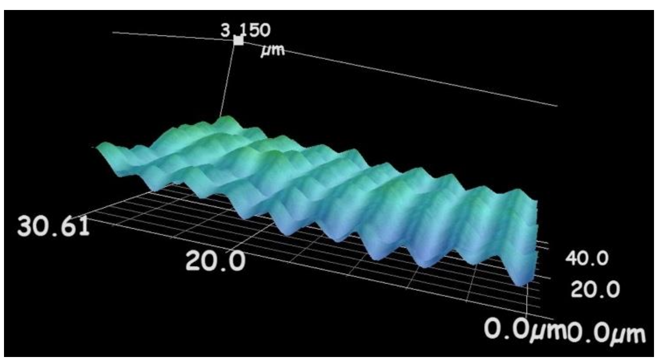
Cost: $3000
Energy Usage: ~29kW per heat exchanger cycle ($0.60/coil)

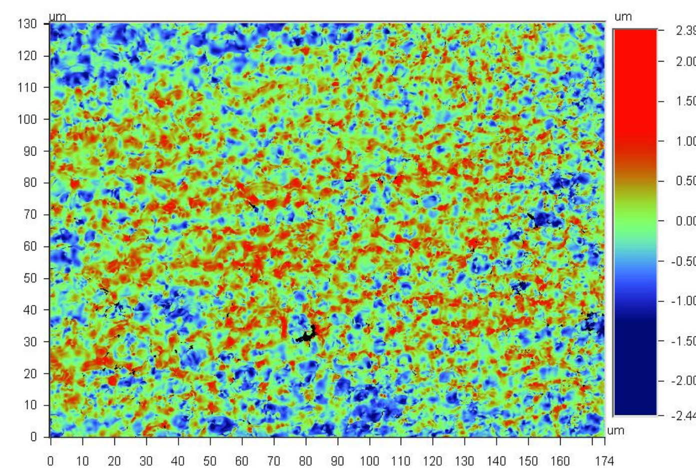
Surface Preparation Approach — Laser Structuring





Samples with different laser structuring conditions



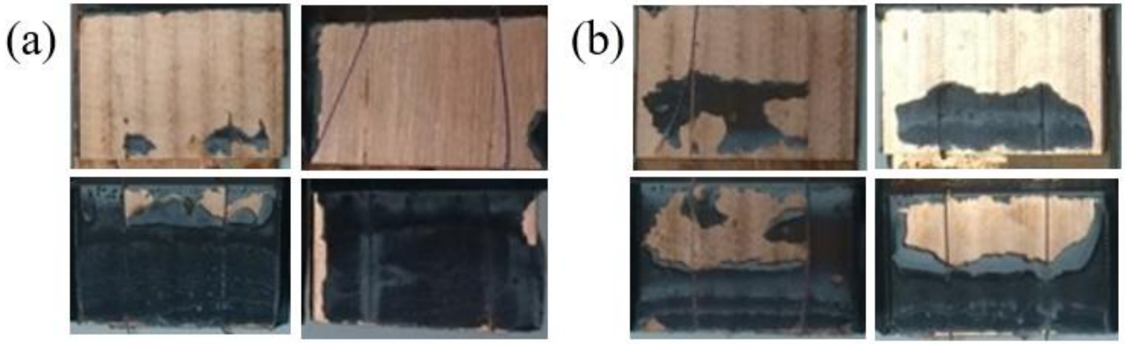


2D surface profile with profilometry

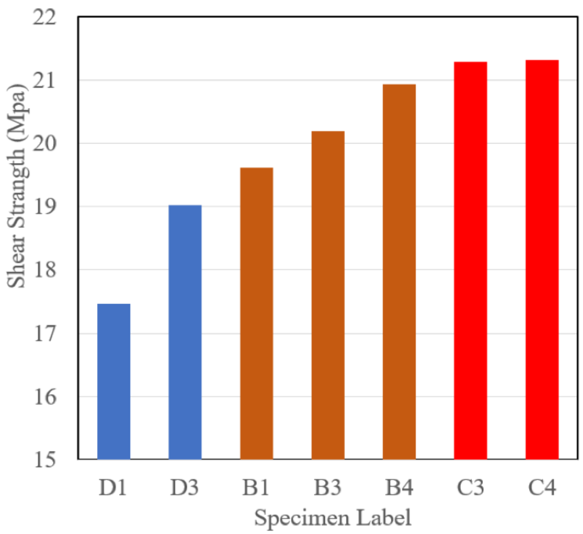
Approach — Laser Structuring Enhancement

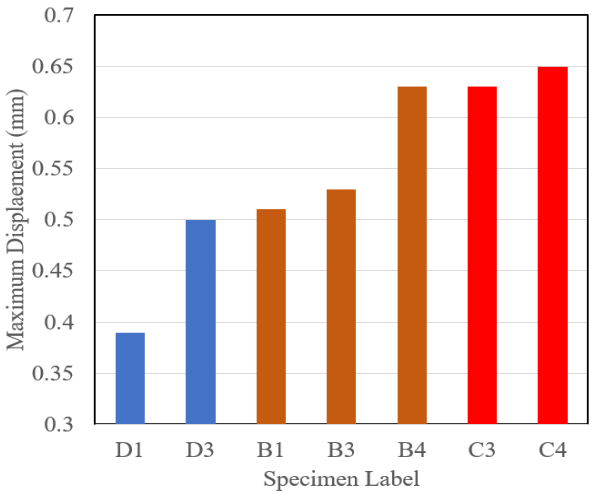
Method:

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



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





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

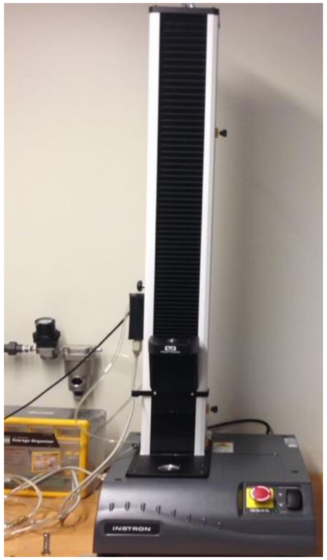
Results:

- 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

Adhesive Characterization Driving ABAQUS Modeling

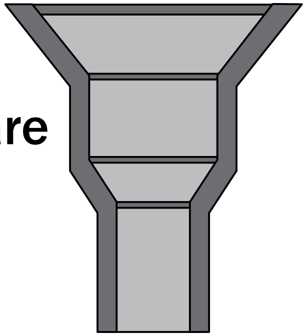
Epoxy adhesive with cohesive failure:

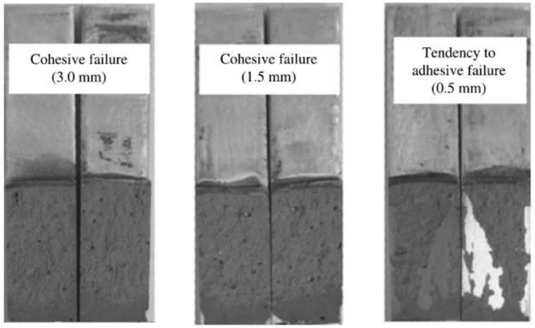
- Fracture toughness: Double cantilever beam (DCB) test; End-notched flexure (ENF) test
- DCB samples will be prepared similarly as for previous studies at Purdue University
- Elastic/shear modulus: tensile/shear test



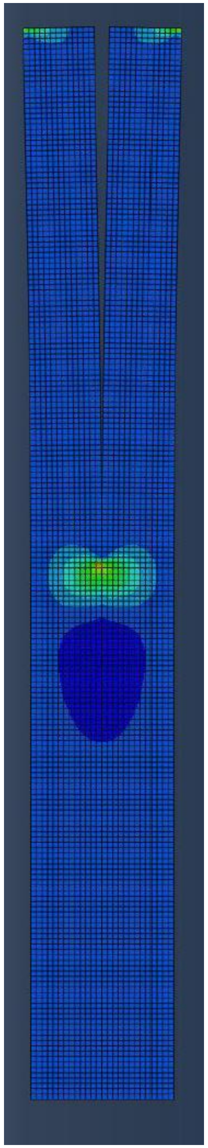
INSTRON 3345

Optimized flare geometry



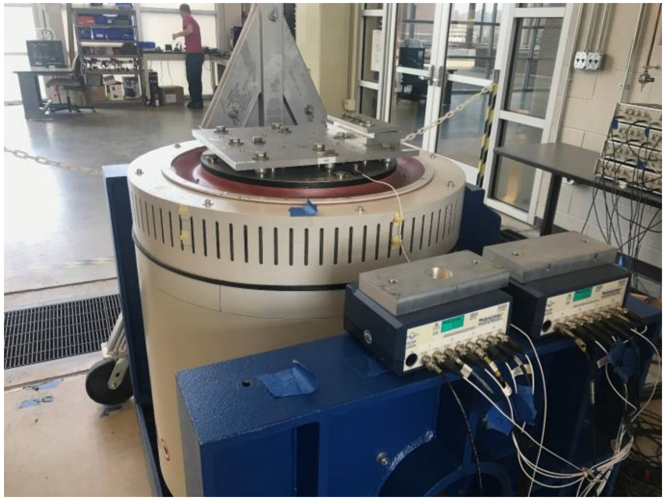


Failure mechanism at the interface



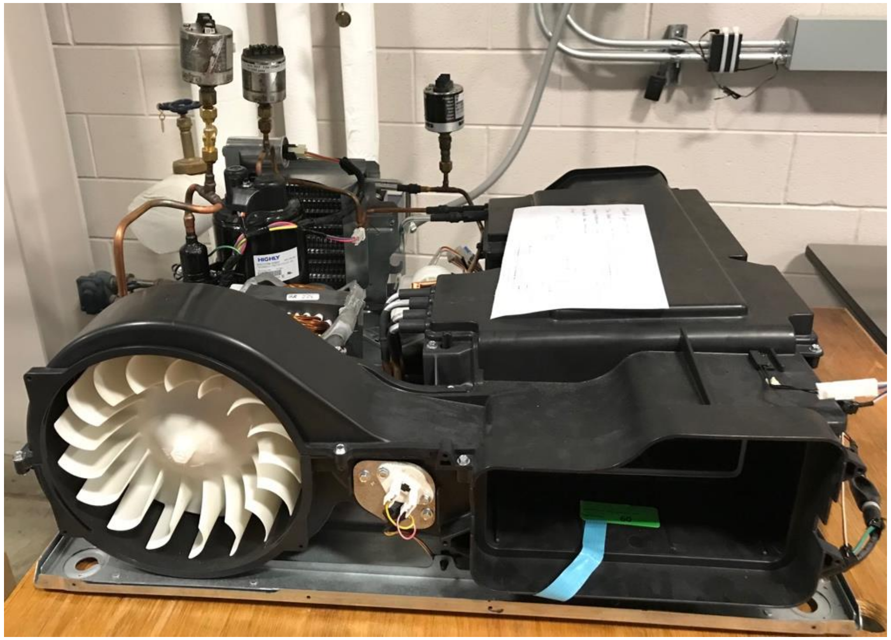
Jibin Han and Thomas Siegmund (2012), "Cohesive Zone Model Characterization of the Adhesive Hysol EA-9394," *Journal of Adhesion Science and Technology*, 26:8-9, 1033-1052.

Approach — System Testing and Demonstration



Vibration testing

Cycling



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 varying response and 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 (>18) to manufacturing plants
- Initial samples formulated for preliminary evaluation

Stakeholder Engagement

Summary of feedback:

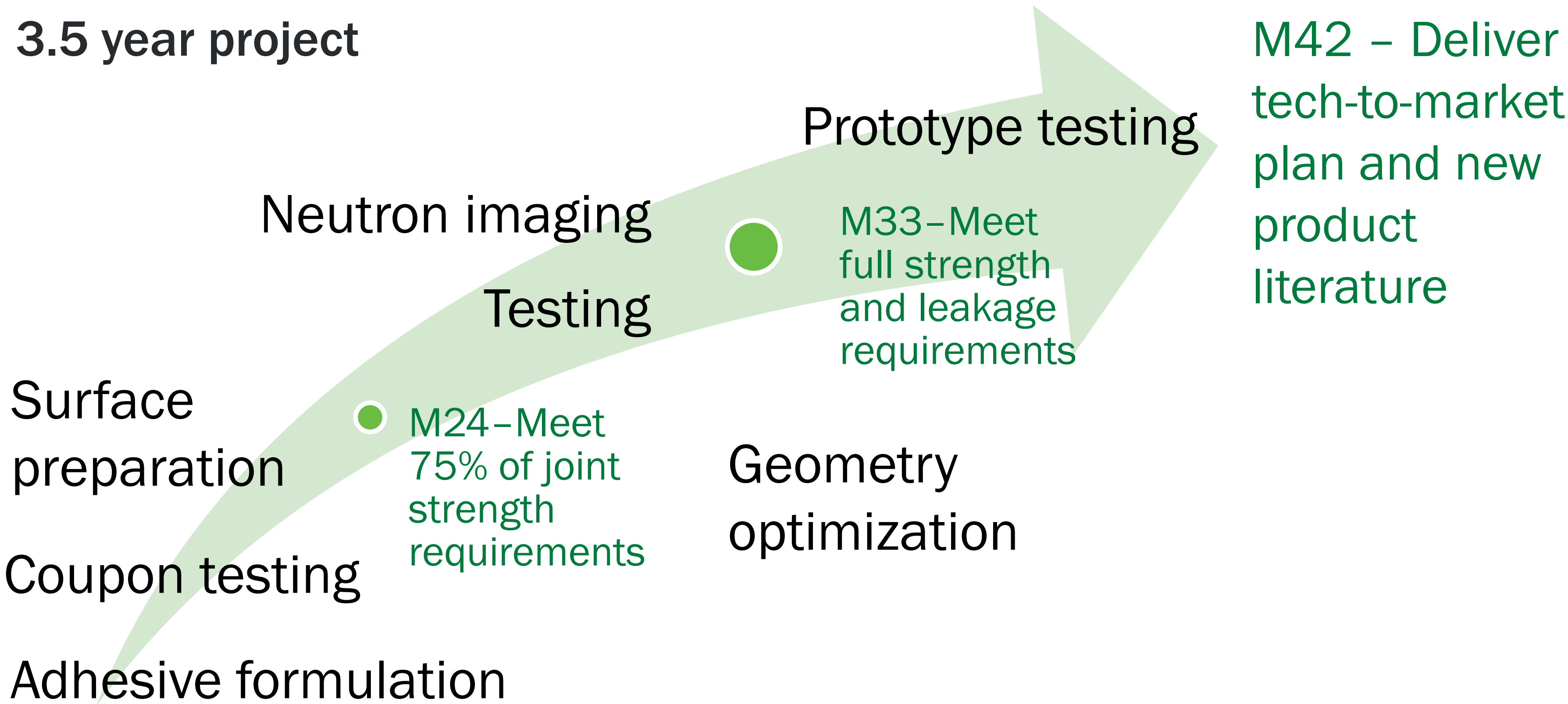
- Value proposition especially for hand brazers under development
- Potential for automation appealing
- Large original equipment manufacturers most interested in the final heat exchanger design
- Working within the limitations set by flaring equipment manufacturers

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



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

Budget History					
10/1/2016– FY 2018 (past)		FY 2019 (current)		FY 2020 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,500K		$0K		$0K	

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							
	◆	Milestone/Deliverable (Actual) use							
	FY2019				FY2020				
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)	
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 stength requirement			◆						
Preliminary cost analysis of current brazing process				◆					
Complete T2M plan and product literature						◆			