Brazing Dissimilar Metals with a Novel Composite Foil

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JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Project ID
LM098

Overview

Timeline

- Start date: September 1, 2013
- End date: August 30, 2017
- Percent complete: 25%

Barrier

- Joining and assembly. High-volume, high-yield joining technologies for lightweight and dissimilar materials need further improvement.

Budget

- Project budget: $595,520
  - Budget Period 1: $144,860
  - Budget Period 2: $149,167

Project Partners

- Dr. Karsten Woll (former postdoc) – now with Karlsruhe Institute of Technology, Karlsruhe, Germany

Relevance – Project Objectives

Overall Objective: Develop and characterize novel reactive foils based on reduction-oxidation (Redox) reactions for use in bonding dissimilar materials

Achievements for FY2014:

- Mechanically fabricated 23 Cu-based and Ni-based Redox Foil systems representing 11 unique chemistries
- Determined baseline strengths for bonding aluminum 6061, magnesium AZ31, aluminum coated boron steel (ACBS), and hot stamped boron steel (HSBS) with Al:CuO-based, Al:Cu_2O-based and Al:NiO-based Redox Foils, that were fabricated using initial techniques.
- Minimized mass ejection from Redox Foils more than 10x through dilution

Milestones

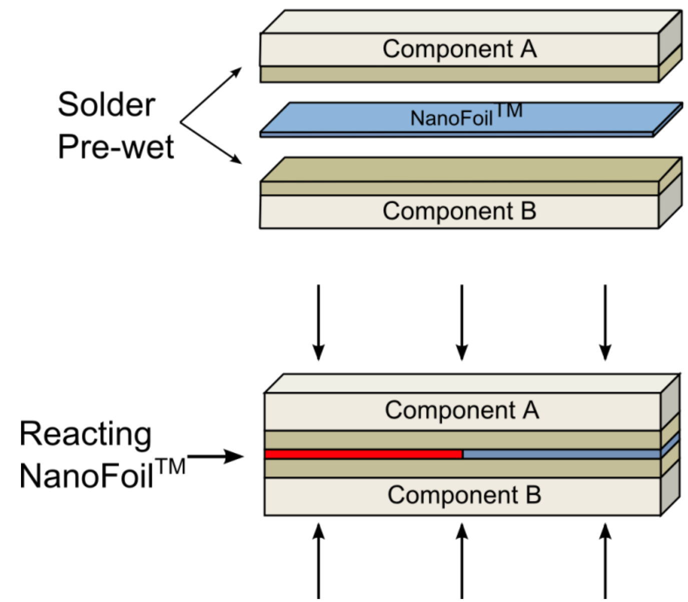
Target Date	Milestones and Go/No-Go decisions	Status
9/30/2015[a,b]	Optimize Redox Foil chemistries and dilutions	On Track
9/30/2015[a]	Optimize microstructures of Redox Foils	On Track
3/31/2016[a]	Optimize mechanical fabrication of Redox Foils	On Track
9/30/2016[a,b]	Determine critical applied pressure for bonding	pending
9/30/2016[a,b]	Identify range of acceptable Redox Foil thickness	pending
12/31/2016[a,c]	Optimize surface preparation methods	pending
12/31/2017	Determine bond strengths and failure modes	pending
9/30/2017	Determine corrosion behavior of optimized bonds	pending
12/31/2017	Determine microstructure/degradation near bonds	pending

[a] Represents Go/No Go Decision; [b]10 MPa bond strength is needed; [c]20 MPa

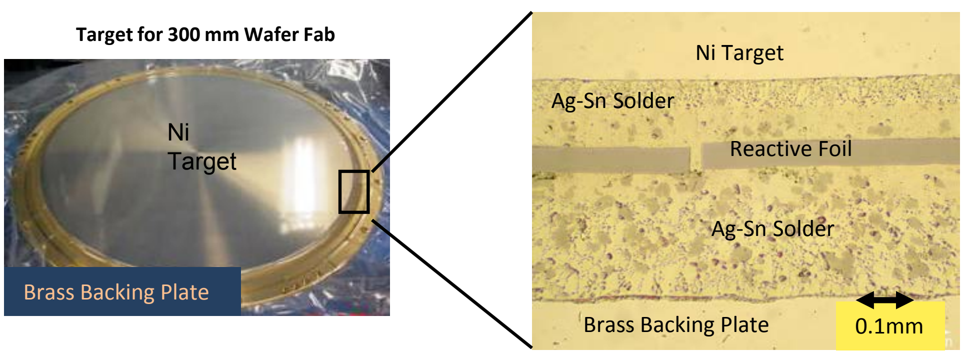
Approach – Existing Technology

- Reactive joining has been commercialized with Al/Ni formation reactions.
  - NanoBond™ process
  - NanoFoil™ (Ni/Al Foils)
  - Local heat source
  - No thermal damage
- Requires pre-wet solder layer
- Expensive due to vapor phase processing of foils

Commercial NanoBond™ Process
(formation reaction)

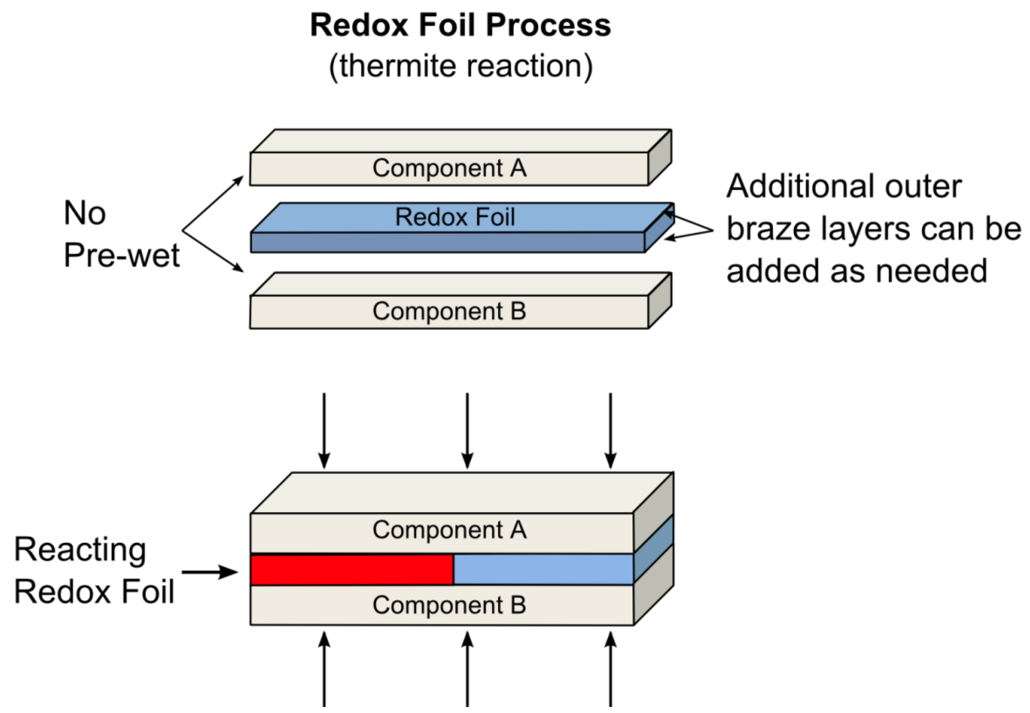


Target for 300 mm Wafer Fab



Approach – Propose Technology

- Joining with Redox Foil
  - Exothermic reaction creates its own braze
  - Little thermal damage (HAZ)
  - Propagates ~0.1 m/s
- Can bond dissimilar metals
  - Ex. Steel to Mg
- Mechanical Fabrication
  - Cheaper than vapor phase processed reactive materials
  - High volume production of Redox foils can be enabled



$$Al + MO + \text{dilution} \rightarrow Al_2O_3 + (M + \text{dilution}) + \text{heat}$$

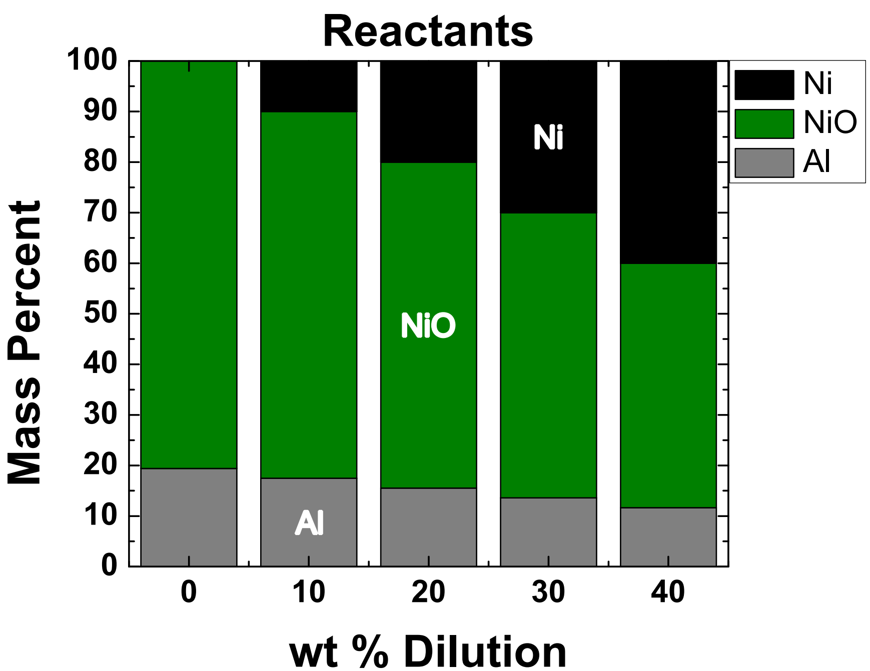
Technical Progress: Fabrication

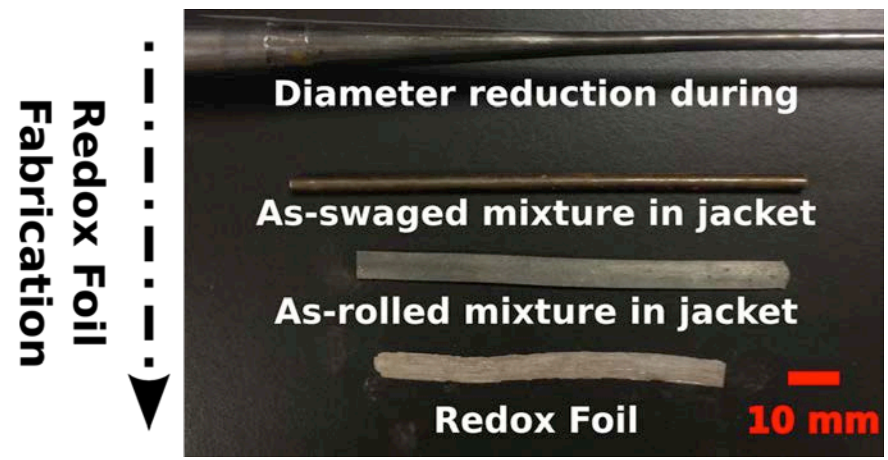
- Redox Foils fabricated by consolidating and processing (swaging and rolling) micron sized powders

Fuel Oxide

Al:NiO:20%Ni

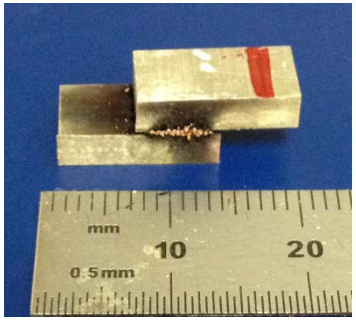
Diluent

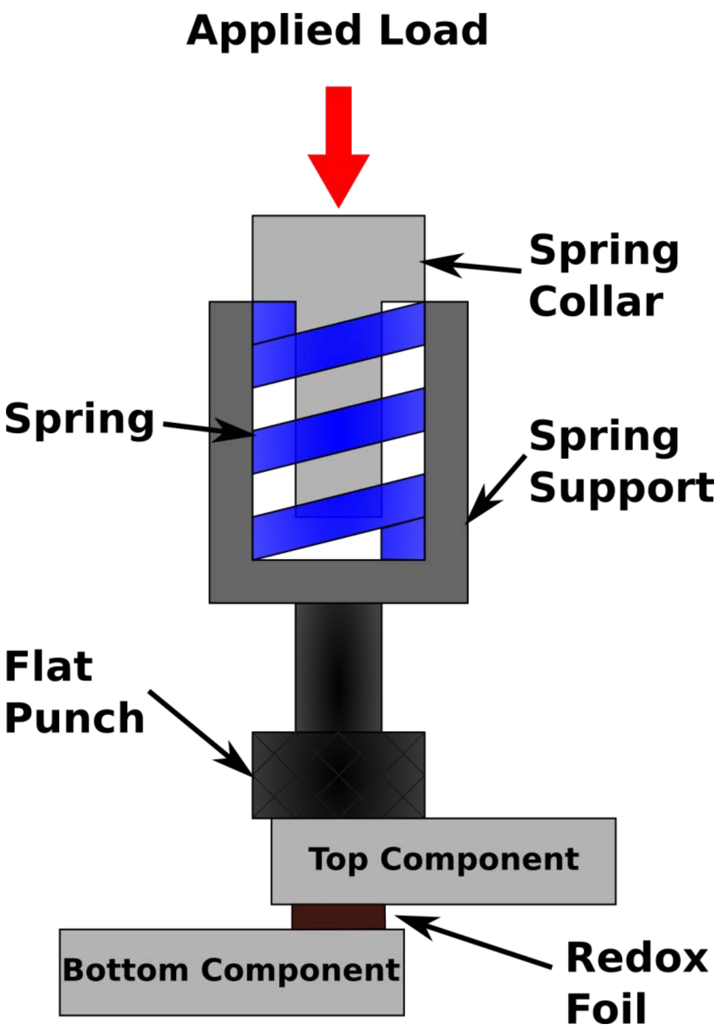




Technical Progress: Bonding Parameters

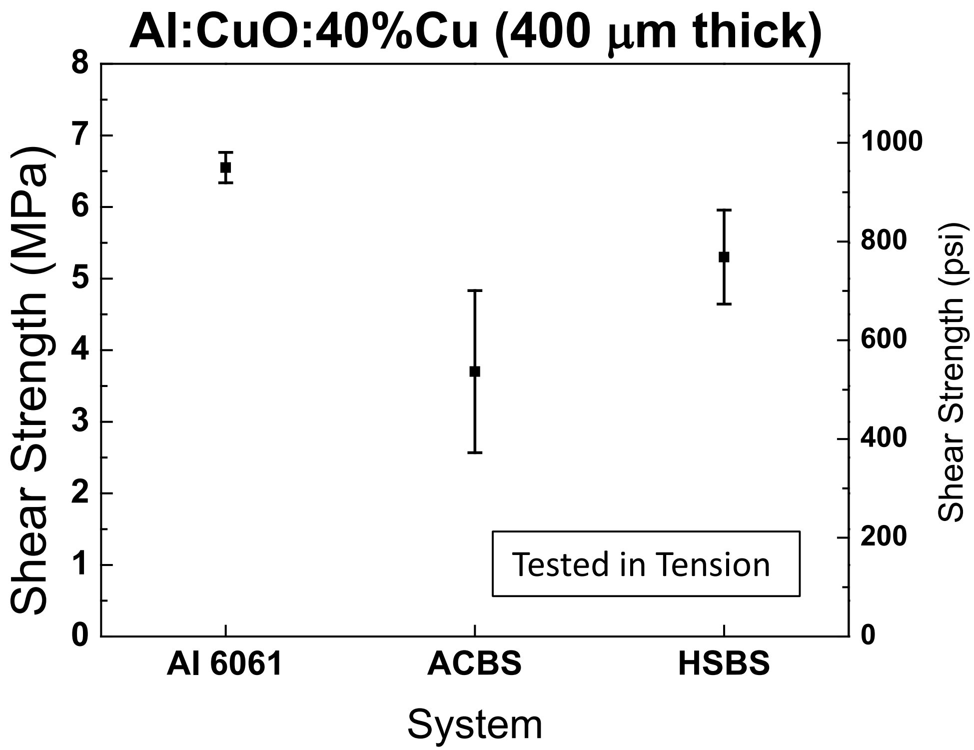
- Constant pressure
  - 13 MPa
  - Maintained by spring
- 400 µm thick foils
- Foils spark ignited outside of bond area
- Base components
  - Al 6061
  - Mg AZ31
  - Al coated boron steel (ACBS)
  - Hot stamped boron steel (HSBS)

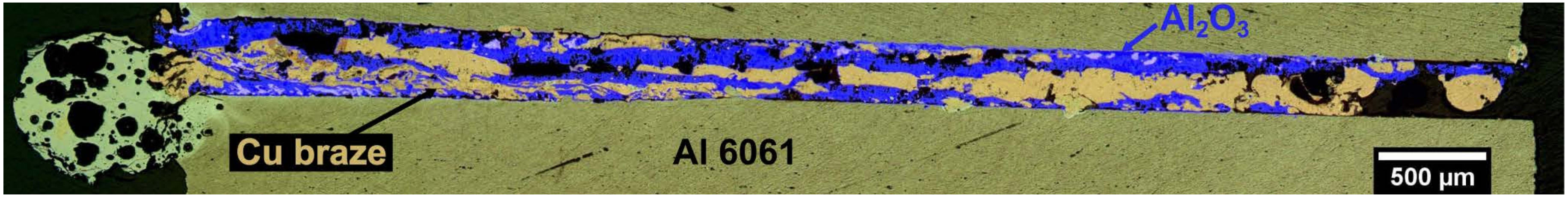




Technical Progress: Bond Strengths

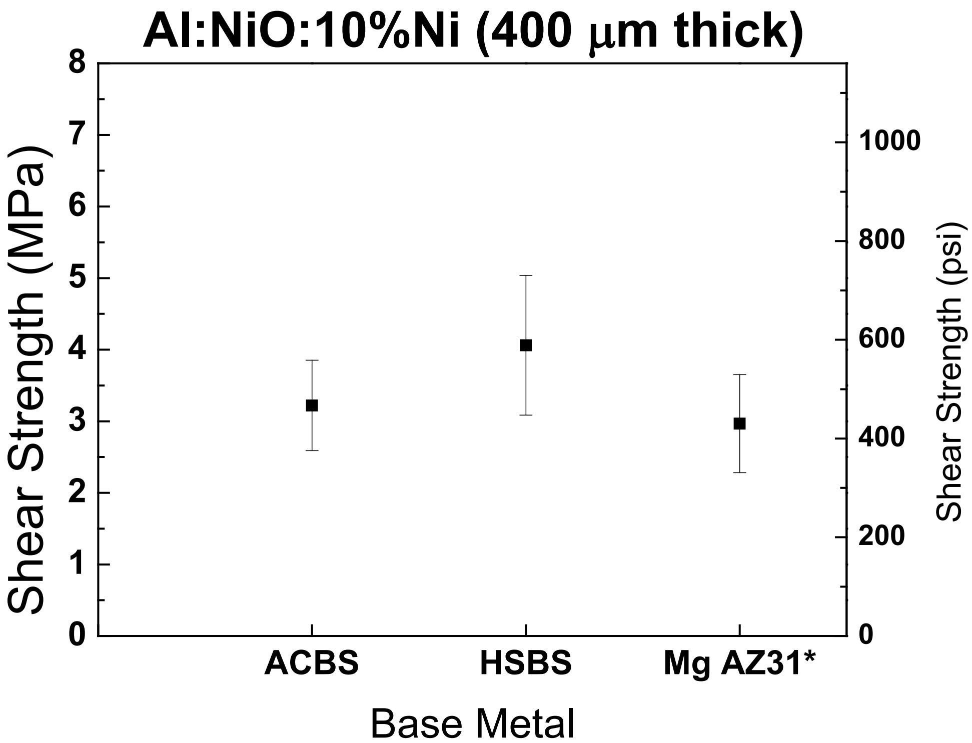
- Copper appears to wet bonding substrates
- Too much flow of material from the bond area
- Flow will be reduced in large bond areas



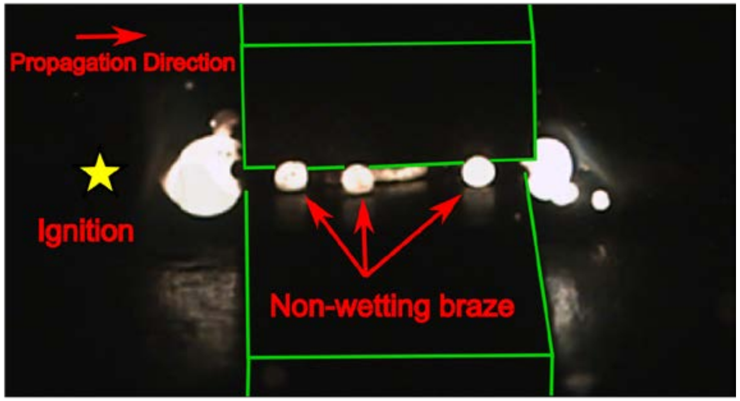


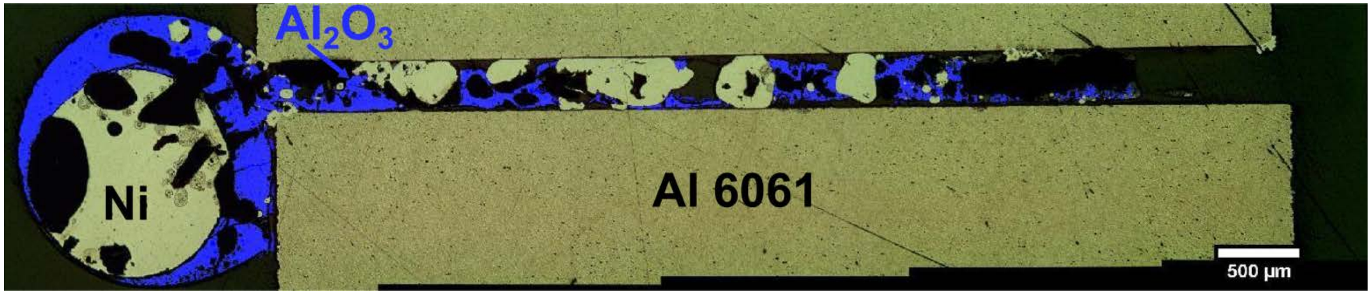
Al:CuO:40%Cu on Al 6061

Technical Progress: Bond Strengths



- Lower bond strength than copper foils
- Nickel braze does not wet substrates well

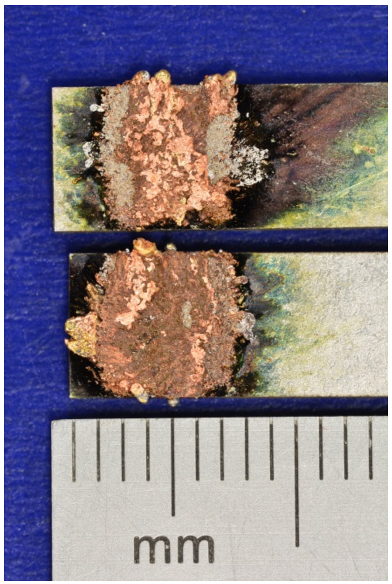




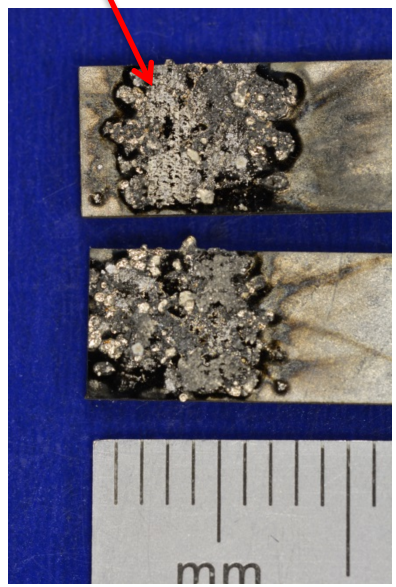
Al:NiO:10%Ni on Al 6061

Technical Progress: Fracture Surfaces

Substrate visible after fracture in bond interface



Al:CuO:40%Cu spreads on both surfaces, fracture within braze

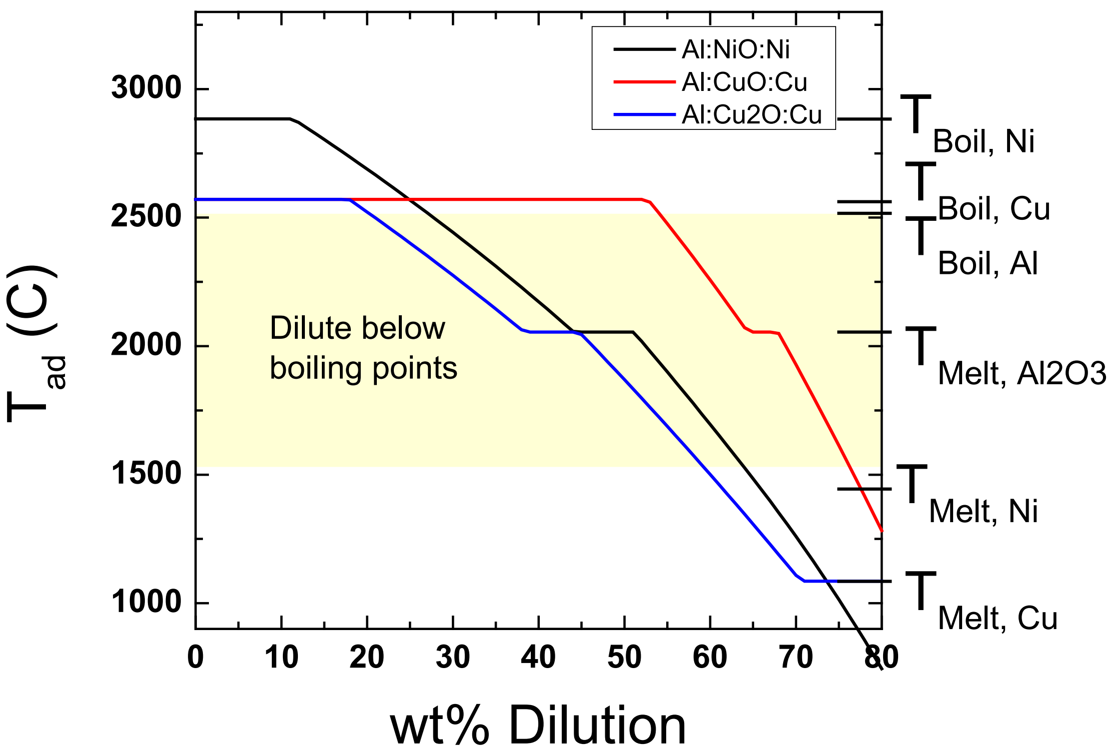


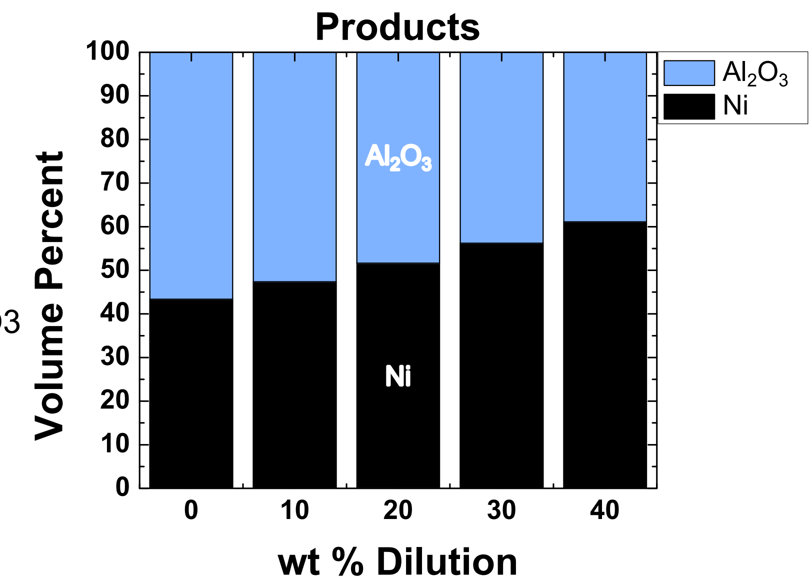
Al:NiO:10%Ni leaves porous braze, fracture at substrate interface

- The CuO/Cu_2O-based foils eject more material but have better wetting
- The NiO-based Redox Foils eject less material but have poor wetting
- **Strategy:** dilute to minimize mass ejection and then alloy to maximize wetting and minimize corrosion

Technical Progress: Dilution

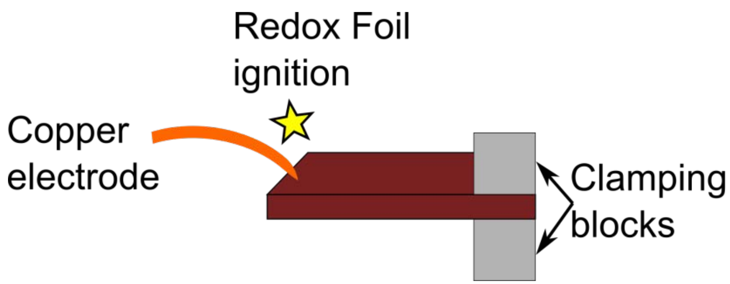
- Dilute foils enough to bring temperature of reaction below boiling points of products (and reactants)
- Dilution provides additional braze material



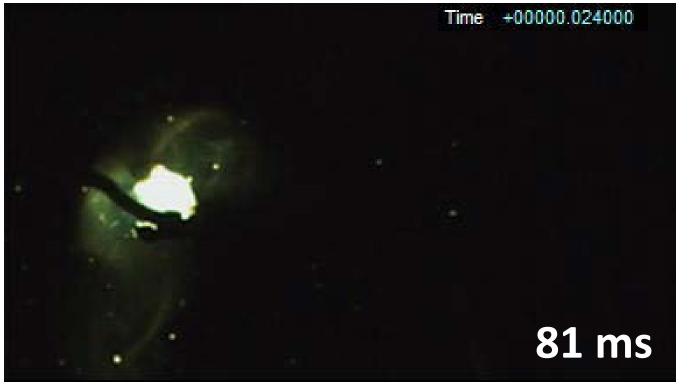


Technical Progress: Propagation

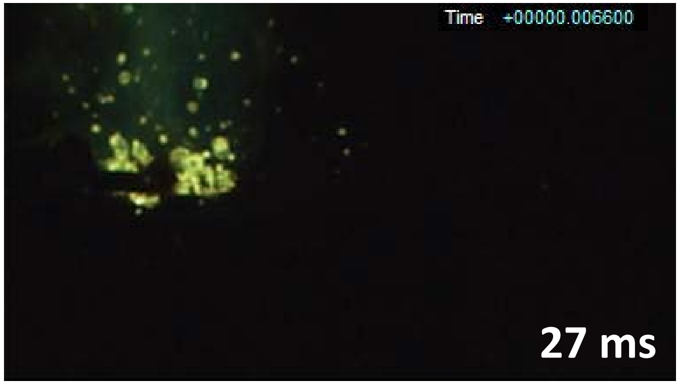
- Mass ejections and propagation velocity depend on chemistry and dilution



Al:NiO:10%Ni

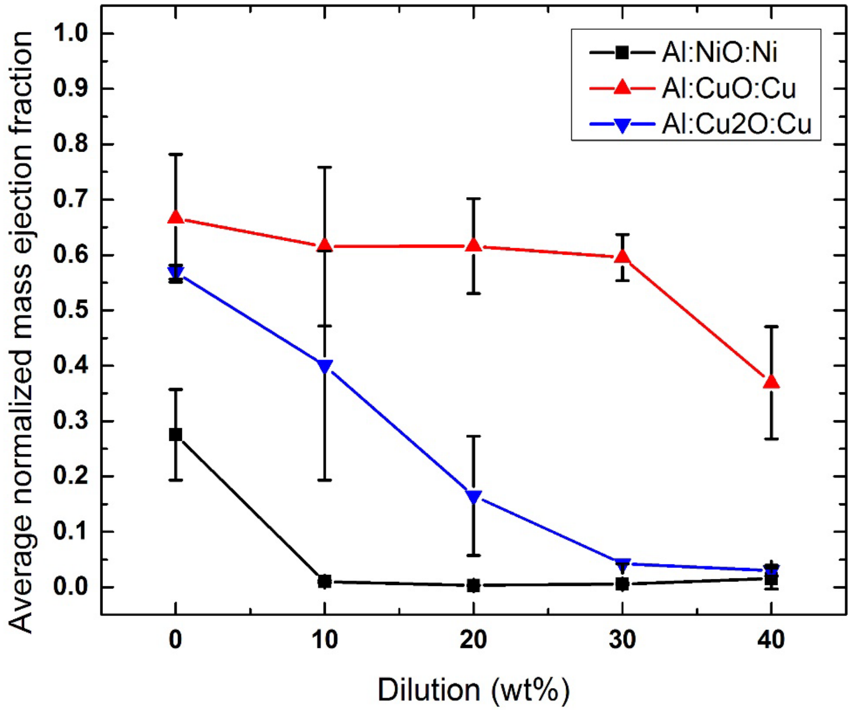


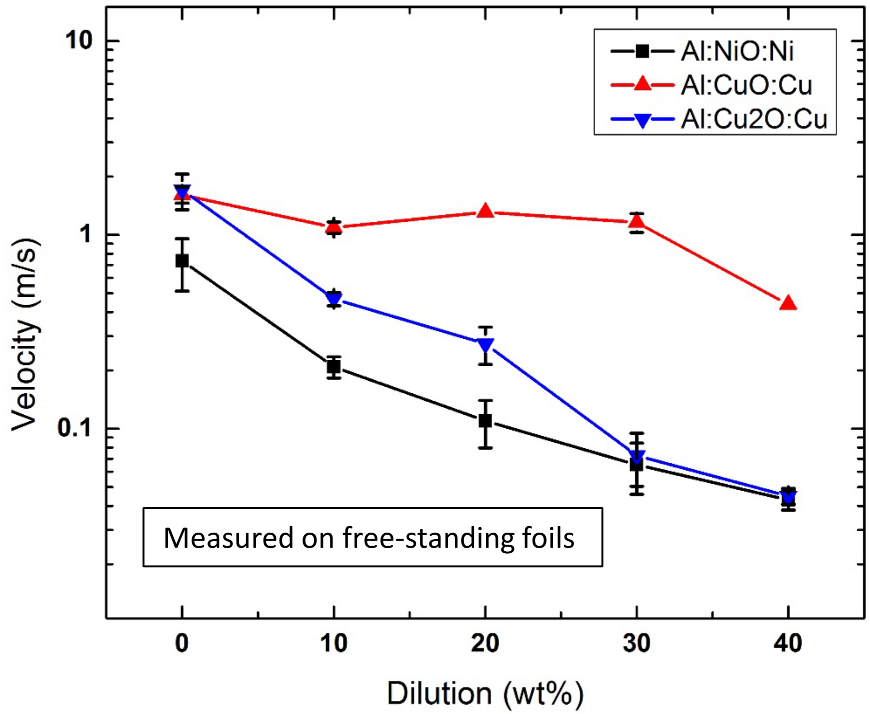
Al:Cu_2O:10%Cu



Technical Progress: Foil Characterization

- As dilution increases, normalized mass ejection and velocity decrease
- Can mass ejection be eliminated without quenching?



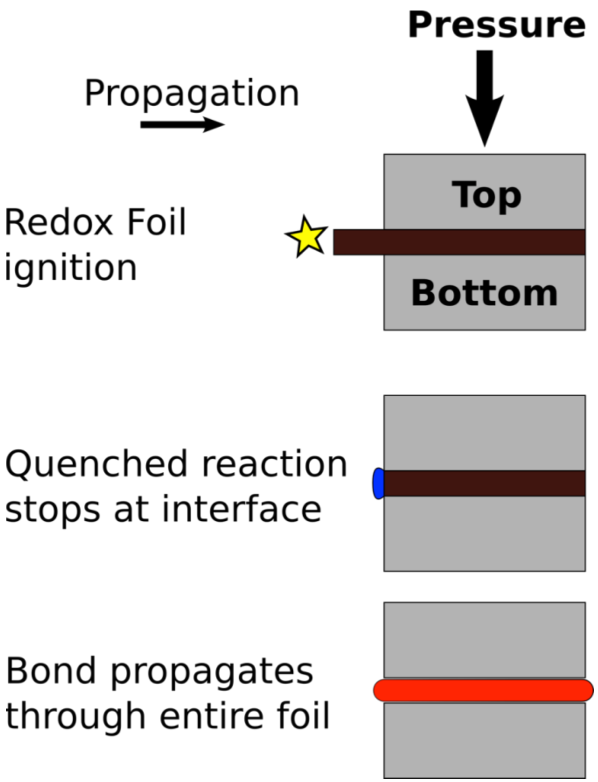


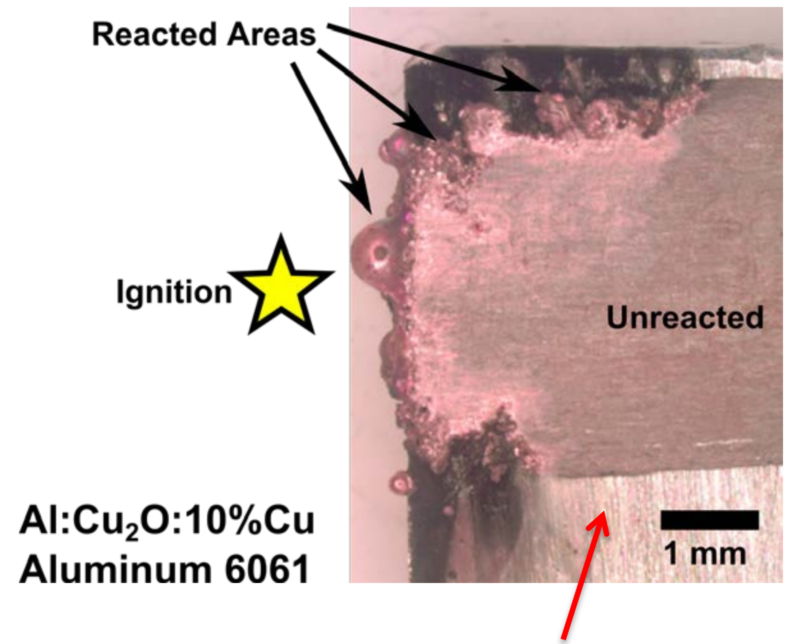
Technical Progress: Quenching in Bonds

- Foils must generate heat faster than heat is dissipated into surroundings or else the reaction will quench

$$\dot{Q}_{RX} > \dot{Q}_L$$

Sum of heat losses, including into substrate, foil, and atmosphere

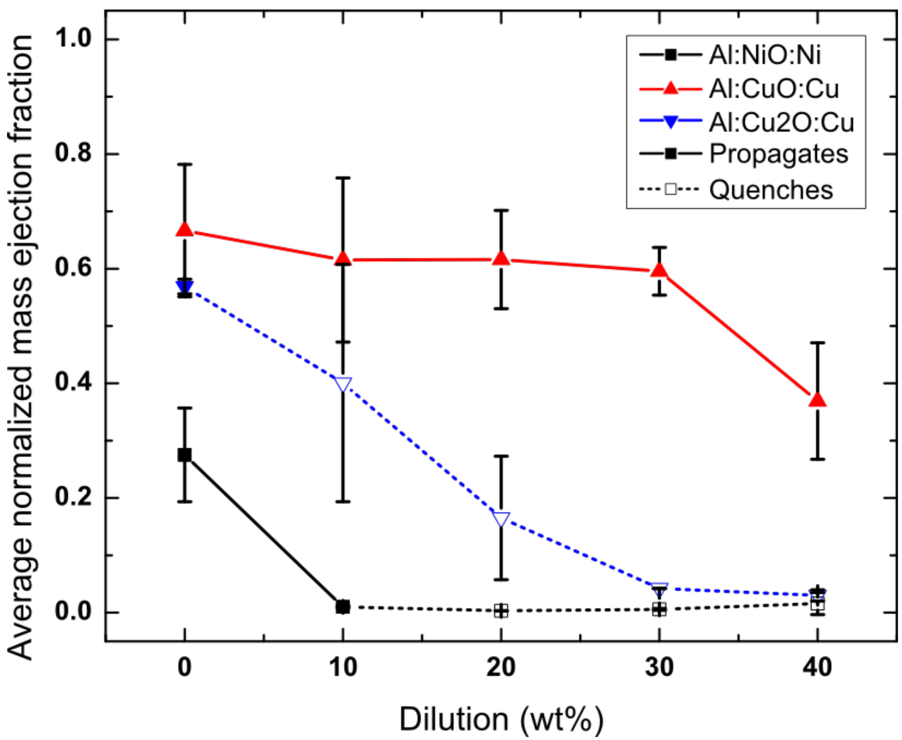


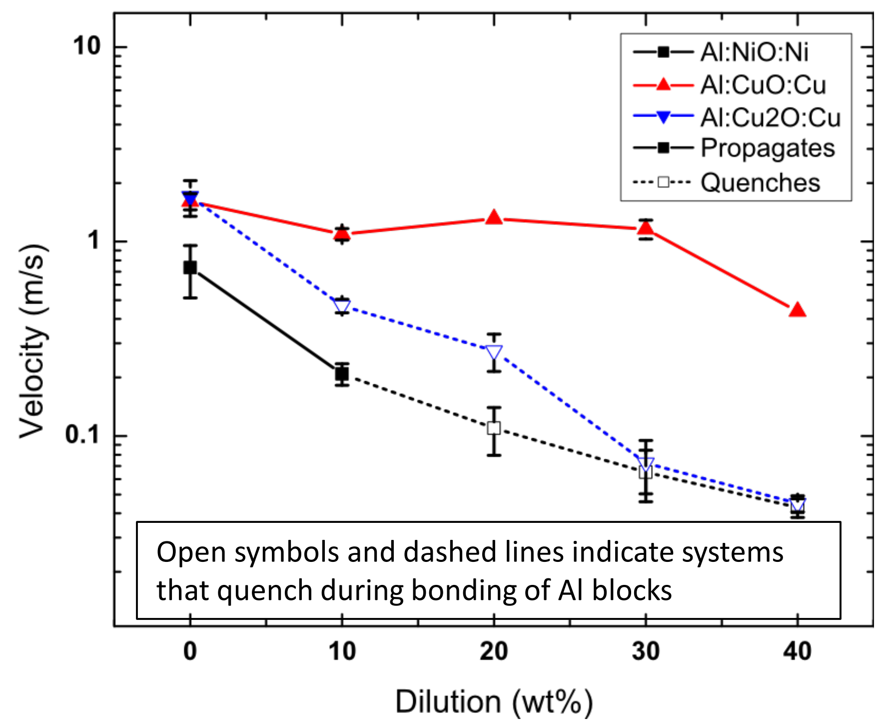


Bottom base substrate after foil ignition and quenching

Technical Progress: Quenching in Bonds

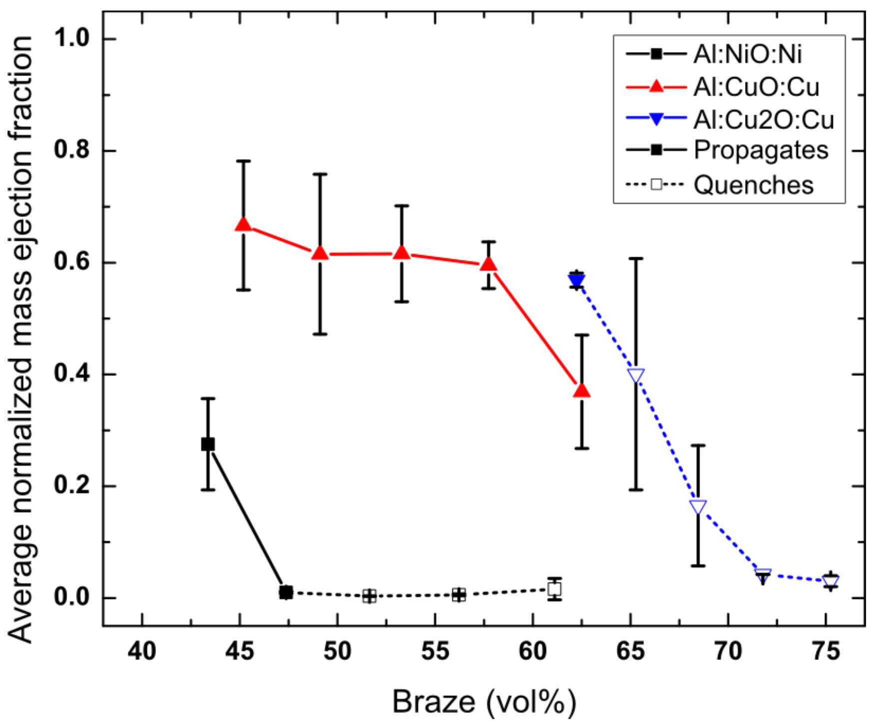
- Large dilutions in NiO and Cu_2O systems lead to quenching in a bond *(indicated by open symbols and dashed lines)*
- Increase reactivity so foils can still propagate within a bond

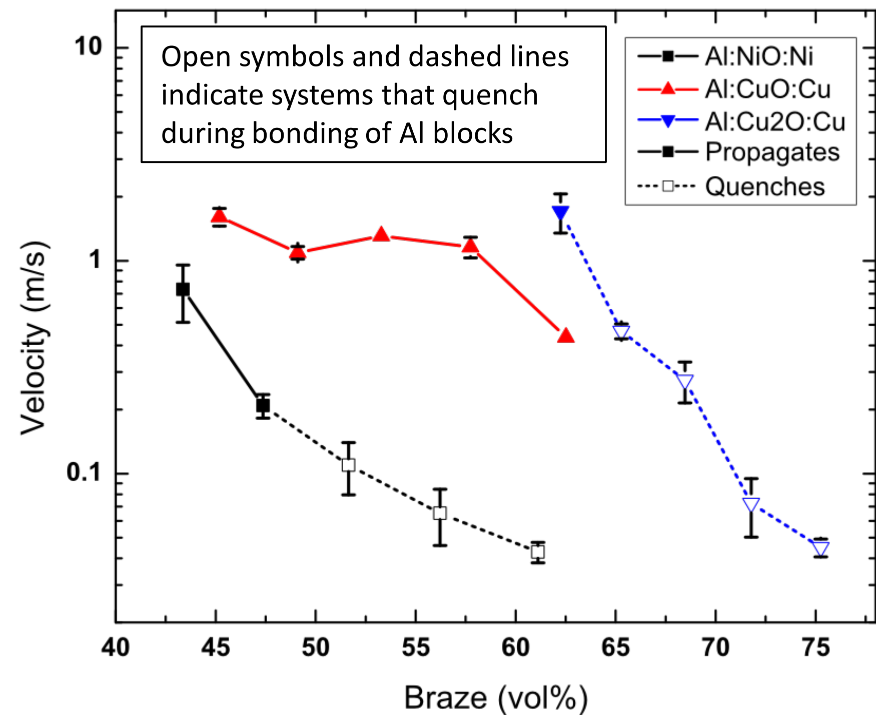




Technical Progress: Quenching in Bonds

- Large dilutions in NiO and Cu_2O systems lead to quenching in a bond *(indicated by open symbols and dashed lines)*
- Increase reactivity so foils can still propagate within a bond
- Larger dilutions will yield larger quantities of braze

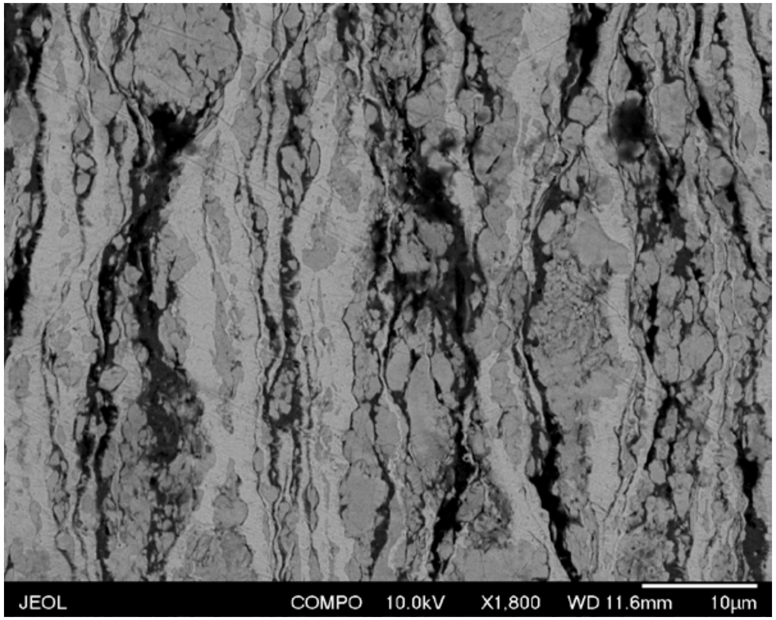




Technical Progress: Enhancing Reactivity

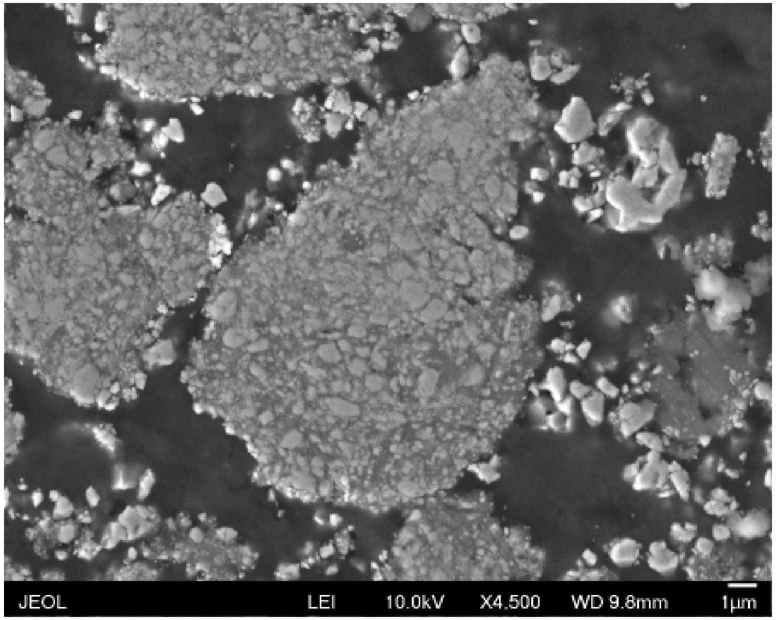
- Decrease reactant spacing via alternative methods (ball milling)
- Incorporate ball milled powder into Redox Foil

Conventional Swaged/Rolled Material



Reactant spacing 1-3 micron

Ball Milled Powder



Reactant spacing < 1 micron

Response to Previous Year Comments

- This project started in October 1, 2013 but was not reviewed in 2014.

Collaborations

- **Severstal** – Material supplier

  Supplied aluminum-coated boron steel and hot-stamped boron steel for testing

- **Dr. Karsten Woll** – Former postdoc

  Now at Karlsruhe Institute of Technology

Remaining Challenges and Barriers

Challenge: Mass ejection & large volume fraction of alumina

Solution: Increase dilution to minimize ejection and increase braze

Challenge: High dilution can lead to quenching

Solution: Decrease average reactant spacing to enhance reactivity

Challenge: Molten braze from Redox reaction wets poorly

Solution: Alloy best braze(s) with reactive elements

Challenge: Best braze(s) may lead to corrosion

Solution: Alloy braze systems to minimize corrosion

Future Work

- Minimize reactant spacing and enhance reactivity so as to maximize dilution
- Identify optimum dilutions for the NiO and Cu_2O systems
  - wt% dilution as well as chemistry
  - Maximize wetting, minimize ejection
- Identify optimum means for combining diluent with reactive particles.
- Create statistically signification datasets for shear strengths of bonds and determine the modes of failure in the joint.

Summary

- Several Ni- and Cu-based Redox systems have been fabricated and studied while varying the level of dilution.
  - Velocity and mass ejection decrease with increasing dilution
  - The amount of braze available to the bond increases with dilution

- Preliminary bonding data suggests that moderate bond strengths can be obtained and depend strongly on foil chemistry and the materials being bonded.

- Further microstructural refinement is needed to promote propagation of the Redox reaction through the bond interface in heavily-diluted foils.

Technical Back-Up Slides

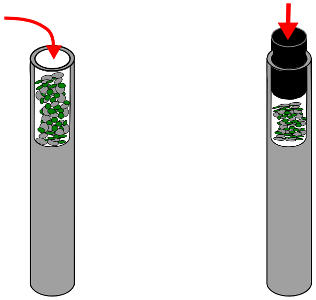
(Note: please include this “separator” slide if you are including back-up technical slides (maximum of five technical back-up slides). These back-up technical slides will be available for your presentation and will be included in the DVD and Web PDF files released to the public.)

Technical Backup: Fabrication

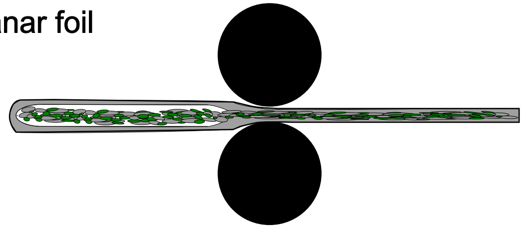
Cold Press Powders - thermite mixtures
(25 C max)

Powders mixed and added to tube

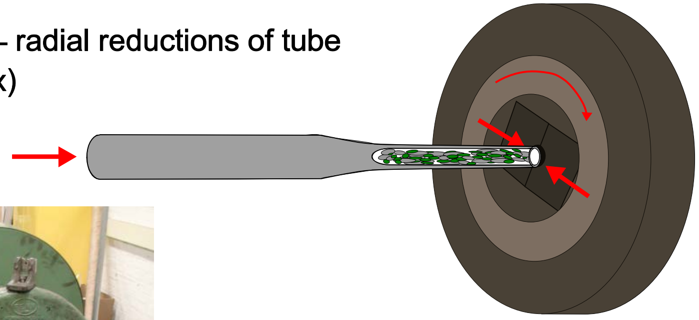
Powders compacted



Rolling - create planar foil
(25 C)



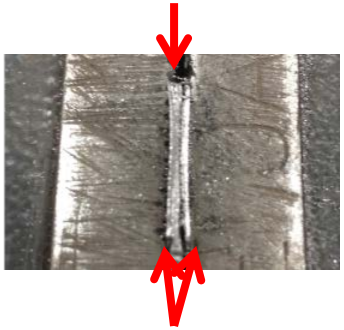
Swaging - radial reductions of tube
(100 C max)



File Jacket leaving foil

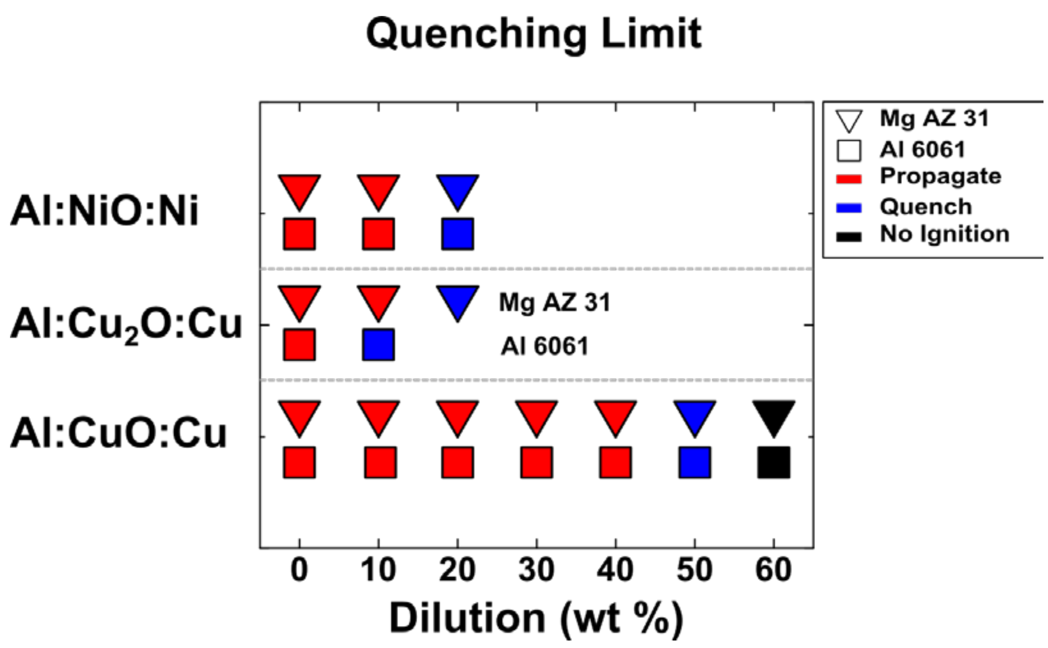
→

Redox Foil



Steel Jacket

Technical Backup: Quenching Limits



Technical Backup: Alternative Diluent