

Collision Welding of Dissimilar Materials by Vaporizing Foil Actuator: A Breakthrough technologies for dissimilar materials joining

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6/18/2014

Project ID # LM086

Overview

Timeline

- Start date - October 2013
- End date – September 2015
- Percent complete – 25%

Budget

- Total project funding
 - DOE share: \$568,499
- Funding for FY14:

Barriers & Targets

- Barriers addressed
 - Joining and assembly of dissimilar materials to create lightweight structures for civil and military vehicles

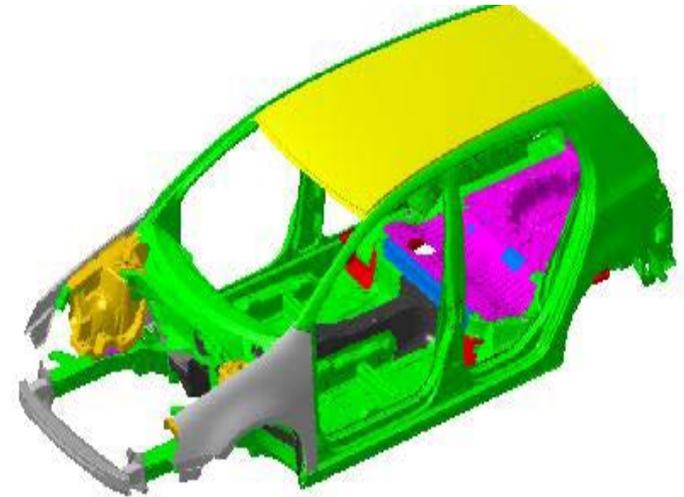
Partners

- Honda: Materials selection, e-coating, industrial adaptation
- Alcoa: Materials procurement
- EWI: Industrial adaptation

Relevance

Objectives

- To utilize a newly developed method called Vaporizing Foil Actuator Welding (VFAW) to create welds between alloys between pairs of two out of three alloy systems which are relevant to commercial and military vehicles: magnesium, aluminum and steel.
- The objective of the current phase (technical feasibility) is to conduct screening tests on 15 different material combinations and downselect 5 pairs for building prototype samples.



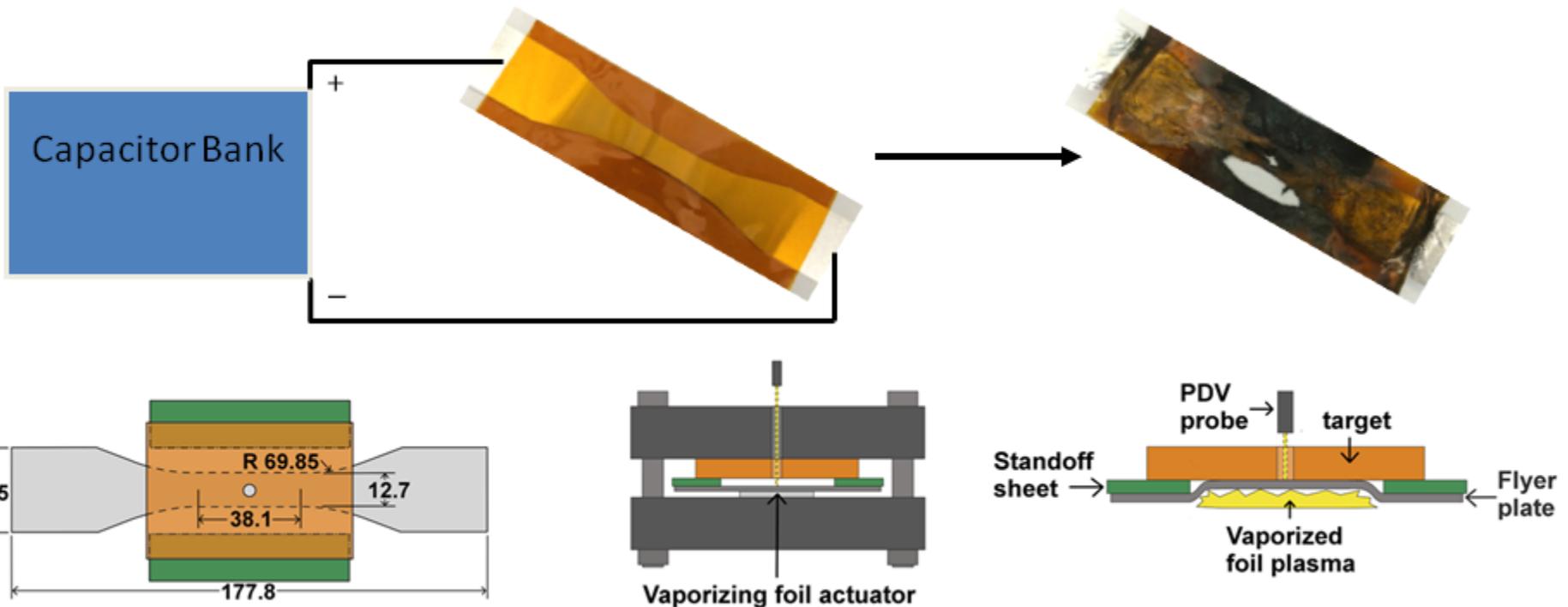
Uniqueness and Impacts

- The uniqueness of this technologies lies in the fact that it entails miniaturization of the collision welding technology to laboratory or typical industrial scale.
- While this project is focused on feasibility testing of a process, if successful, it can help overcome significant barriers in the development and use of multimaterial structures.
- The 2nd phase of the project also aims to develop corrosion mitigation strategies for such structures

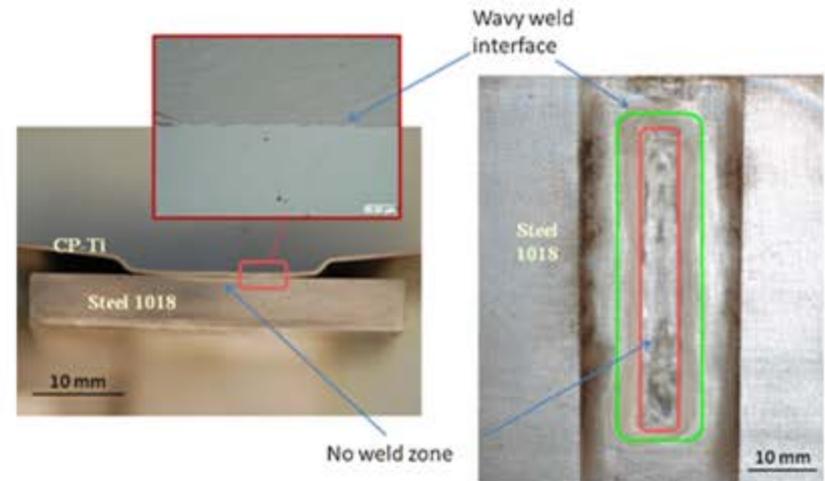
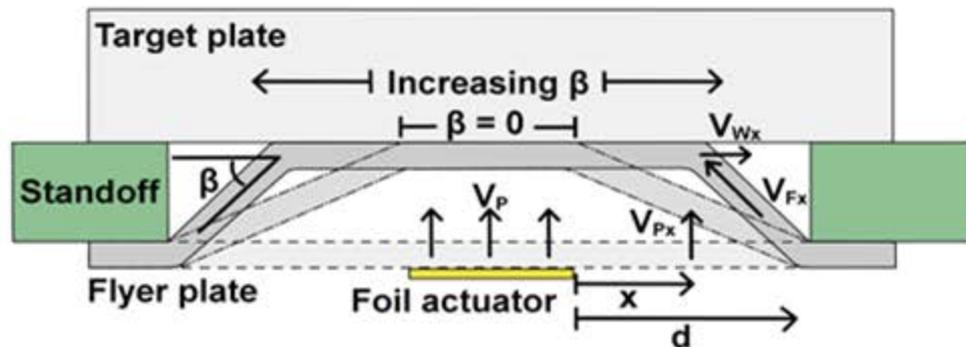
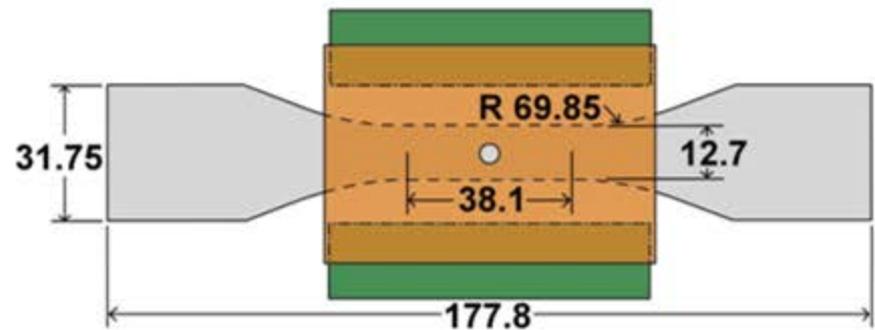
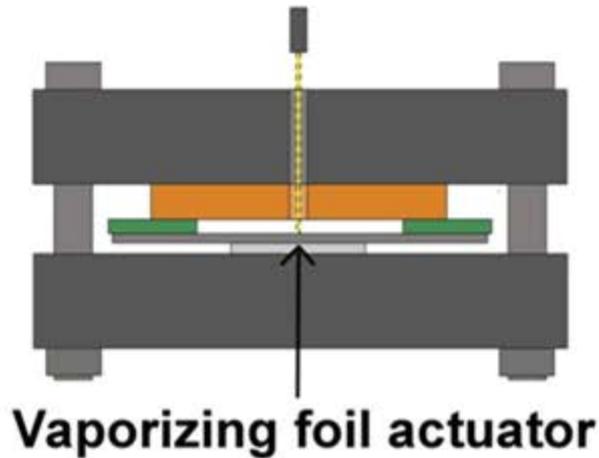
Approach: Basic Method of VFAW

When the energy deposition rate is very high, a thin conductor can be heated far above its energy of sublimation due to the constraint of inertial and magnetic forces.

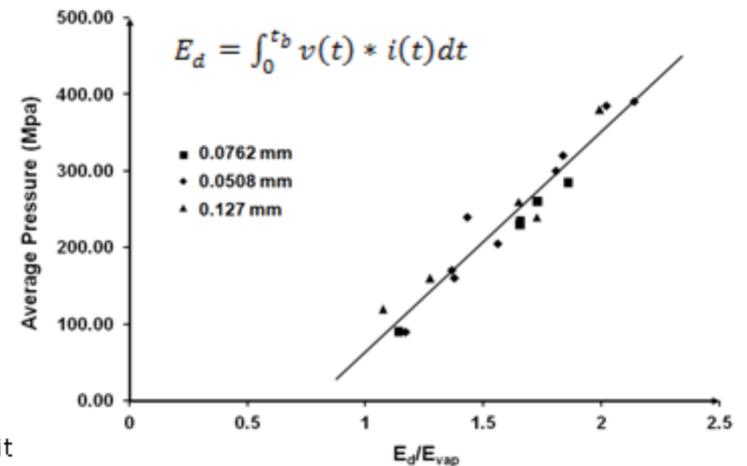
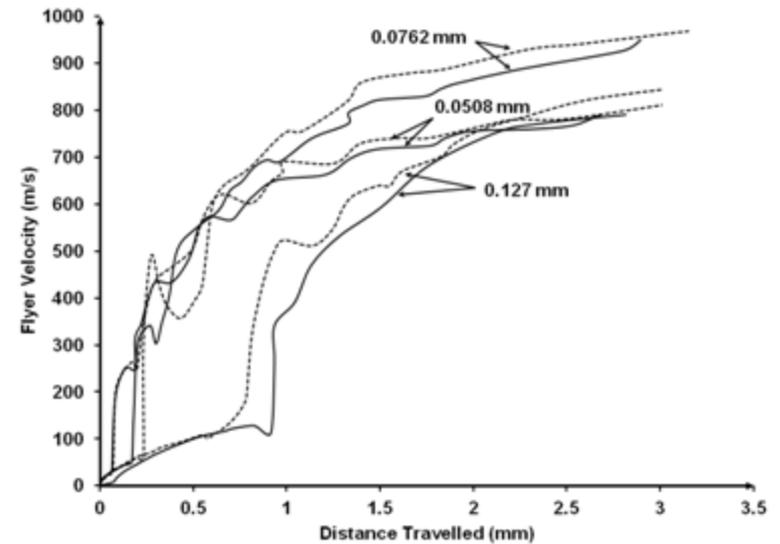
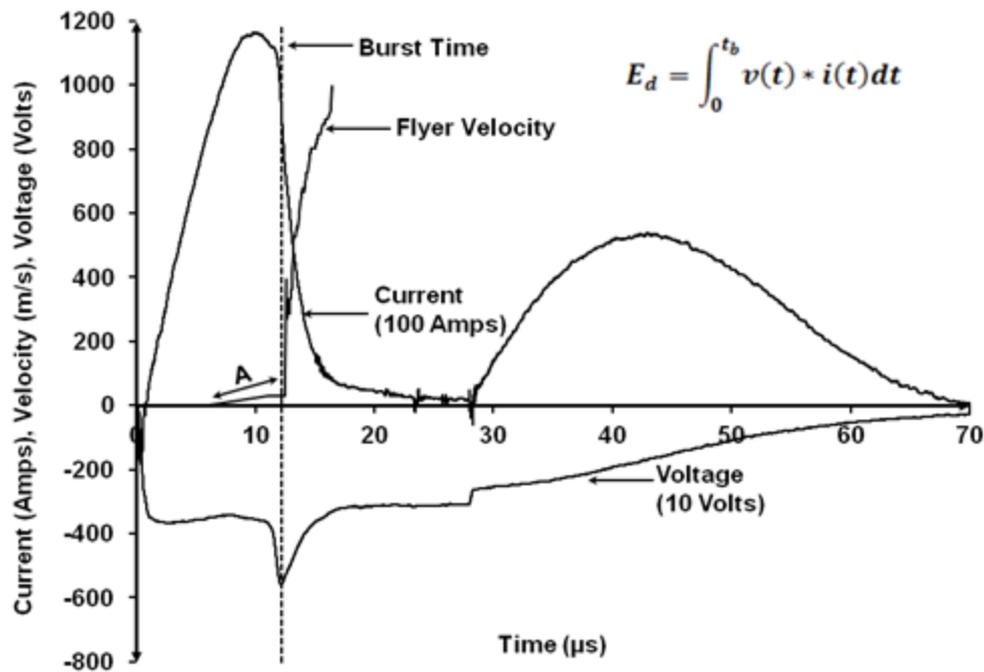
When these inertial forces let go, the conductor vaporizes and the stored energy is released as a pressure pulse.



Approach: VFA Welding II

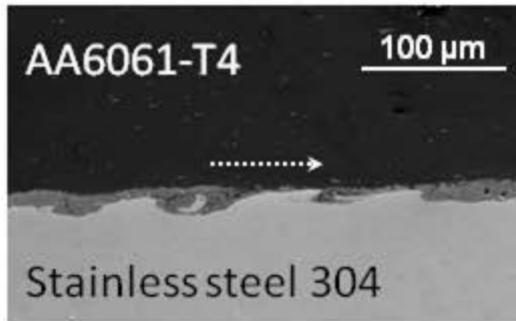


Approach: Process Detail

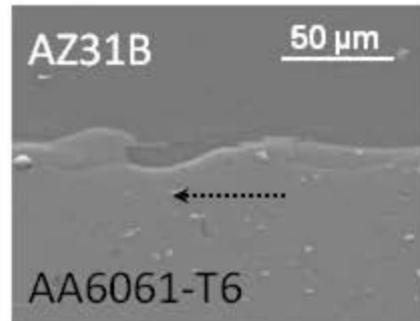


- Vivek, A., Hansen, S.R., Daehn, G.S., 2013, "Vaporizing foil actuator: controlling the pressure pulse for impulse based metalworking", Accepted for MSEC, Detroit

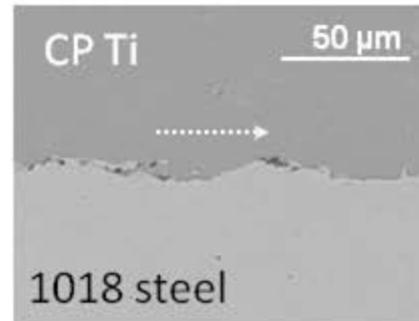
Approach: Dissimilar Welds



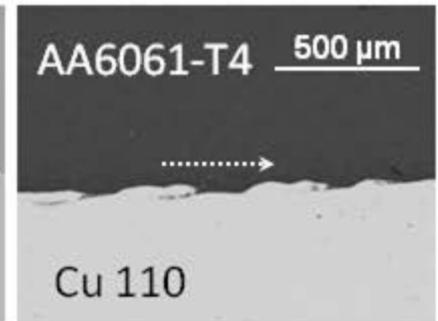
16 N/mm



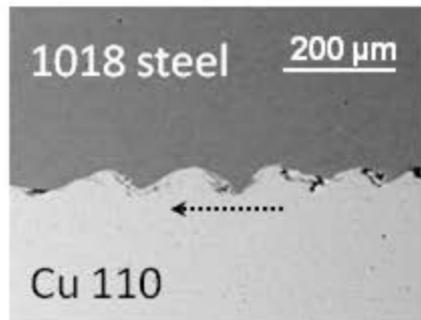
3 N/mm



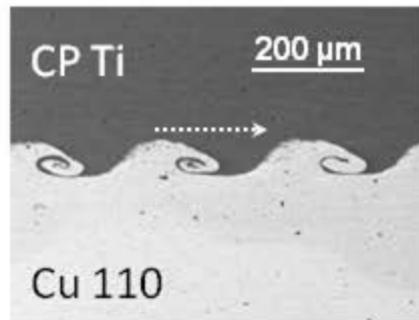
8 N/mm



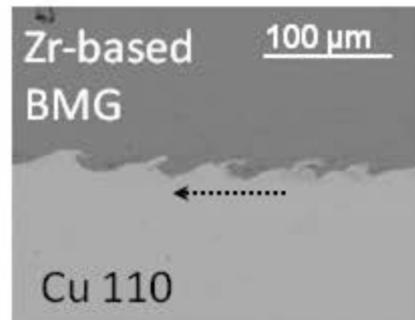
Failed in aluminum



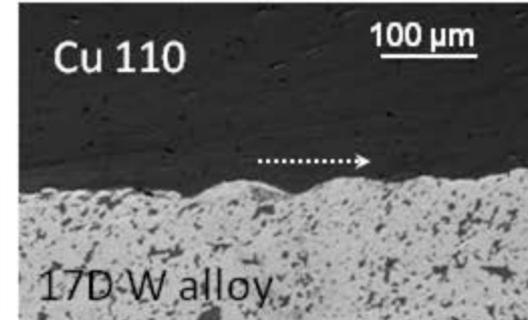
Failed in copper



Failed in copper



Failed in copper



Failed in copper

Approach: Year 1

Selection of materials and systems

Goals: Industrially useful strong and corrosion resistant desired couples

Honda and EWI assist in selection of 1mm thick sheet alloys and corrosion strategies.

Pairs to be joined:

Al-Fe, Fe-Mg, Mg-Al and Fe-I-Al, Mg-I-Fe

When corrosion potentials $< \sim 0.25$ V different, intermediate layer may be needed. 3-layer bonding is feasible based on preliminary work.

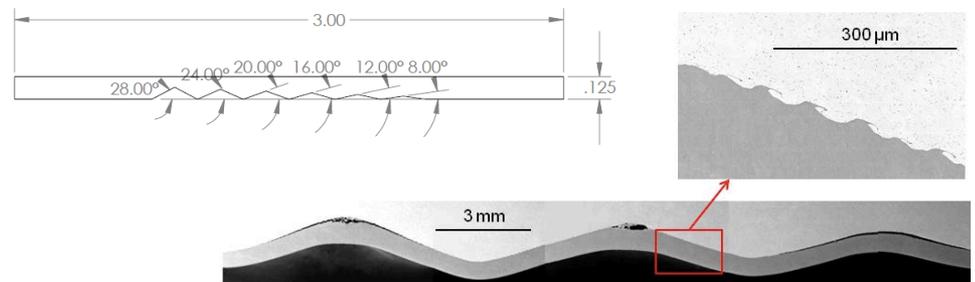


Screening and parameter determination

15 material pairs, chosen for structural utility and corrosion subject to screening of a matrix of 4 measured collision velocities and 6 collision angles in each shot,

each bond will be examined for peel strength and microstructure.

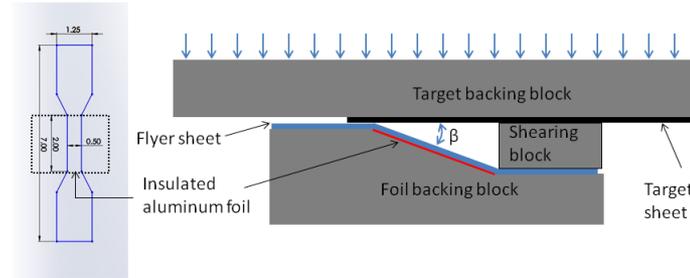
Very rapid screening will allow study of 360 separate conditions.



Approach: Year 2

Fabrication of lap shear joints

Based on optimal collision angles measured in phase II, fixtures will be built that provide optimum collision angles with and without corrosion interlayers. 5 systems based on Al-Fe, Fe-Mg, Mg-Al, will be fabricated; 8 samples of each.



System joint testing and characterization:

Prototype will be tested with and without e-coat

- Lap Shear Testing – ASTM

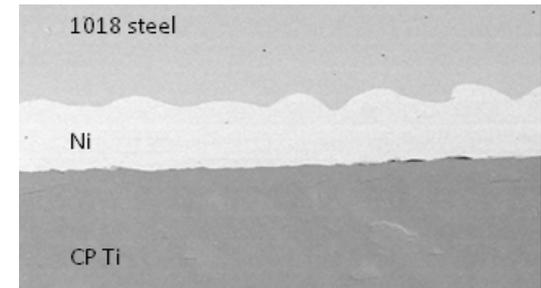
- Salt Fog Testing (MIL-STD 202 G or similar)

- Lap shear testing of salt fog exposed samples

- Joint microstructure using optical and electron microscopy

- Microstructure characterization of joint-induced defects

- Characterization of joint failure modes (shear and peel)



Scale up and commercial viability

Ongoing interactions with Honda and EWI will keep work guided to utility

Small efforts in: determining limits of vaporizing foil method with respect to geometries possible and length and area of foil that can be vaporized and developing a design methodology.



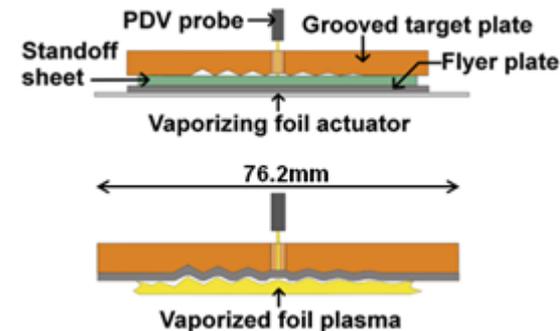
Technical Accomplishments and Progress

- The VFAW system for conducting screening tests was built
- Grooved target plates were machined out of selected materials
- Flyer sheets were launched with different input energies into vaporizing foil actuators

- 4 combinations of metal pairs tested:

- AM60B/AA6061-T4 (successful welding in most grooves)
- AM60B/AA5052 (successful welding in some grooves)
- HSLA (a588)/AA6061-T4 (unsuccessful)
- HSLA (a588)/AA5052 (unsuccessful)

- For the pairs that did not weld successfully, couple of strategies were implemented:
 - introduction of a thin interlayer made of one of the parent materials
 - Welding to a flat target plate
- Both these strategies were found to be **successful** in creating good welds
- The results for each pair are depicted in the following few slides



Technical Accomplishments and Progress

Magnesium AM60B/AA6061-T4

Successful welding conditions:

- Low angles, high impact velocities
- The wavelength of the interfacial waves were quite high with higher impact angles and there is greater chance of delamination of sample

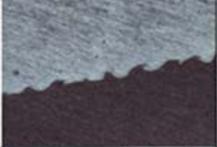
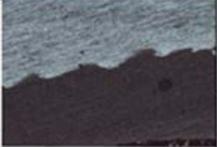
Collision angle	Collision velocity, energy	488m/s 4kJ	640 m/s, 6 kJ	660m/s, 7 kJ	787 m/s, 8 kJ	822 m/s, 10 kJ
8°	No weld					
12°	No weld					
16°	No weld					
20°	No weld					
24°	No weld					
28°	No weld					

Technical Accomplishments and Progress

Magnesium AM60B/AA5052

Successful welding conditions:

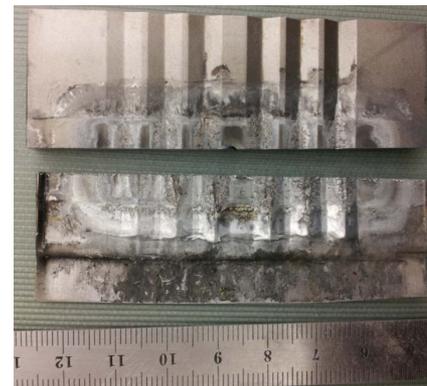
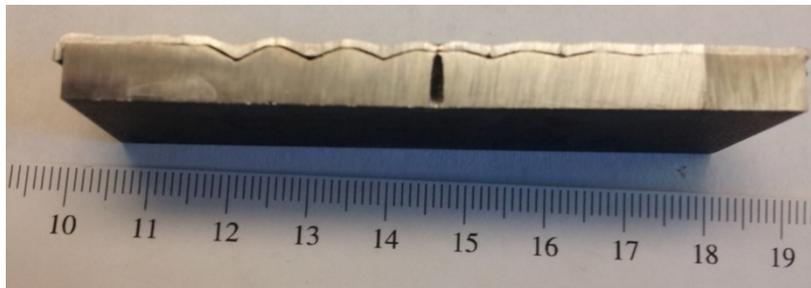
- similar to the AM60B/AA6061-T4

Collision velocity, energy Collision angle	550m/s 6kJ	650 m/s, 8 kJ	720 m/s, 10 kJ	745 m/s, 10 kJ	792 m/s, 12 kJ
8°	No weld	No weld			
12°	No weld	No weld			
16°	No weld	No weld			
20°	No weld	No weld	Peeled while cutting	Peeled while cutting	Peeled while cutting
24°	No weld	No weld	 Peeled while cutting	Peeled while cutting	Peeled while cutting
28°	No weld	No weld	Peeled while cutting	Peeled while cutting	Peeled while cutting

Technical Accomplishments and Progress

HSLA 588a/AA6061-T4 and HSLA 588a/AA5052

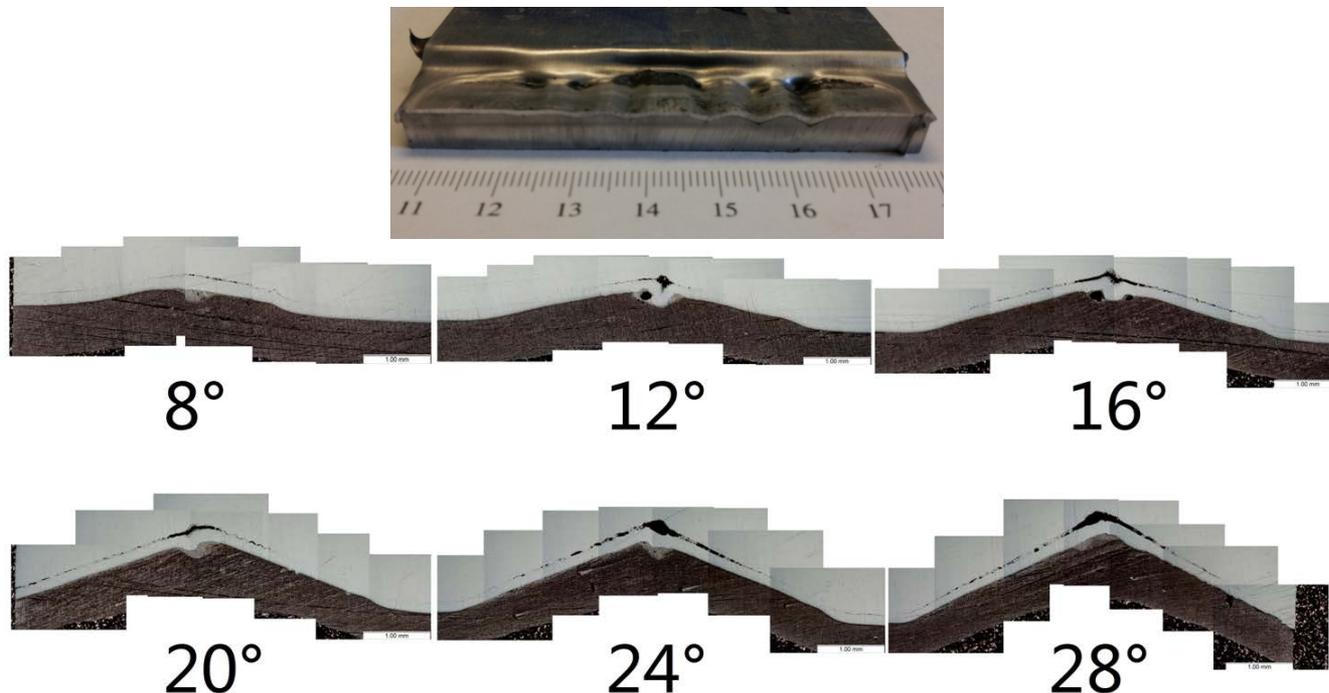
- Screening experiments always yielded samples which were either already split after the experiment or came apart during sectioning
- This could happen because of the following reasons:
 - Air rebound: The air trapped between the flyer and the target could cause a rebound. Adiabatic compression of the trapped air can also cause substantial heating which could melt the flyer and/or target surfaces.
 - Shock heating: The energy deposited at the interface could be too high.
 - Staggered timing of welds: Since the welds being created in different grooves non-simultaneously have diverse strengths, it is possible that one of them is rebounding while the others are still welding.



Technical Accomplishments and Progress

HSLA 588a/AA6061-T4 and HSLA 588a/AA5052

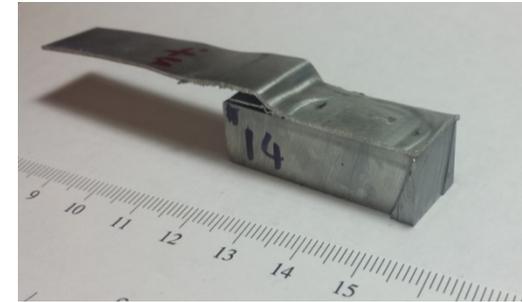
- We were able to deal with those issue in the following ways:
- Introduction of a AISI 1018 or AA6061 interlayer
- Shown here is a HSLA grooved target welded to AA6061-T4 sheet with 0.16mm thick AISI 1018 steel sheet placed in between the target and flyer during the VFAW experiments



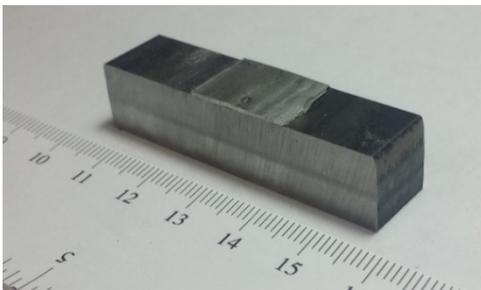
Technical Accomplishments and Progress

HSLA 588a/AA6061-T4

- Welds created with 10 kJ input energy, and peeled
- Target: ½” thick 588a plate, Flyer: AA6061-T4
- Experiments done with no, AA6061, and 1018 interlayers

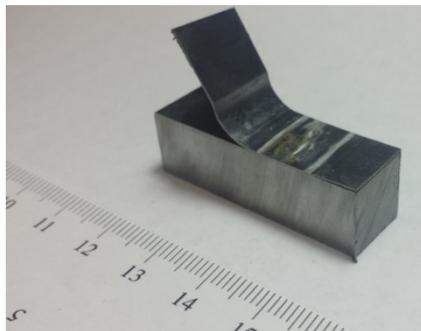


no interlayer



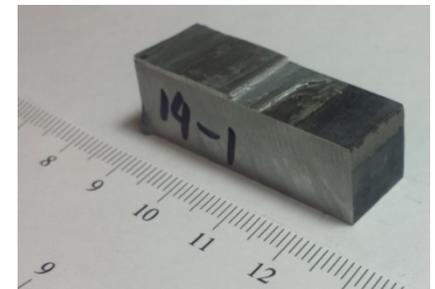
Failure location: parent aluminum

1018 interlayer



Failure location: aluminum-1018 interface

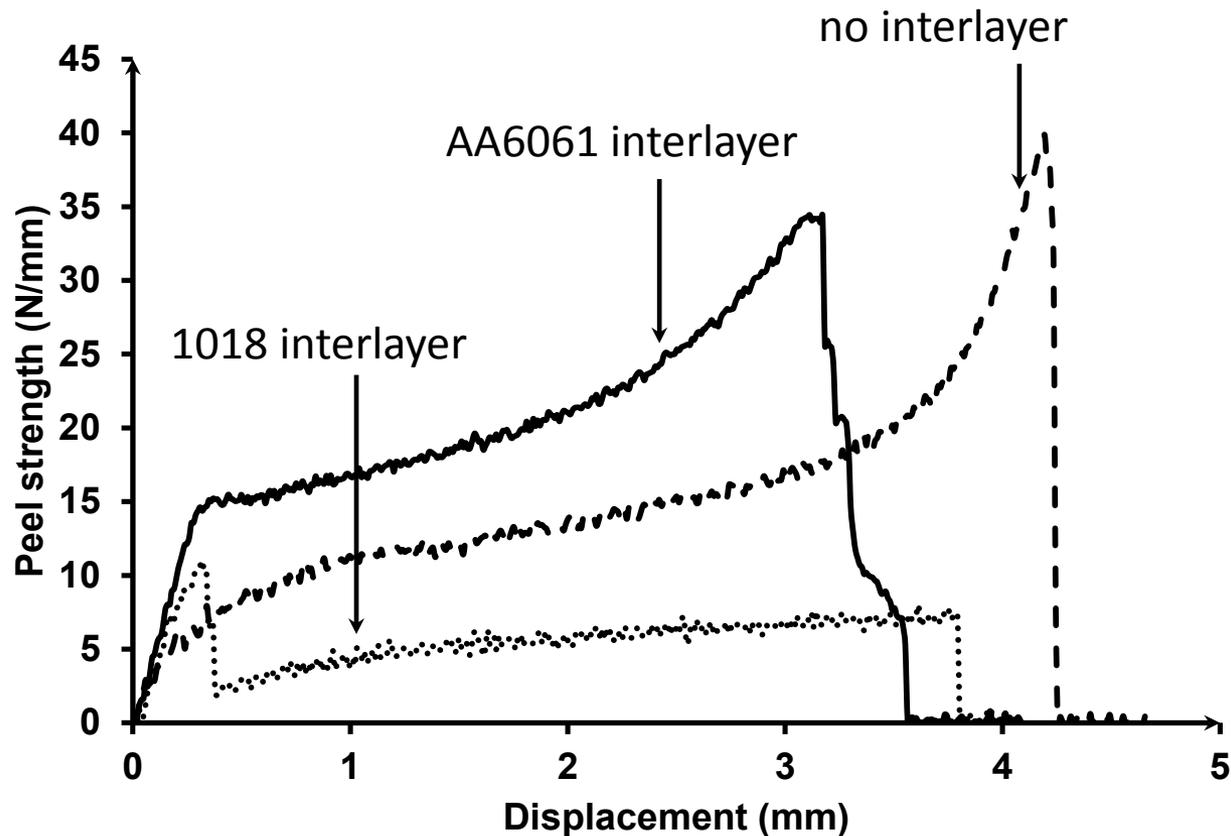
AA6061 interlayer



Failure location: parent aluminum

Technical Accomplishments and Progress

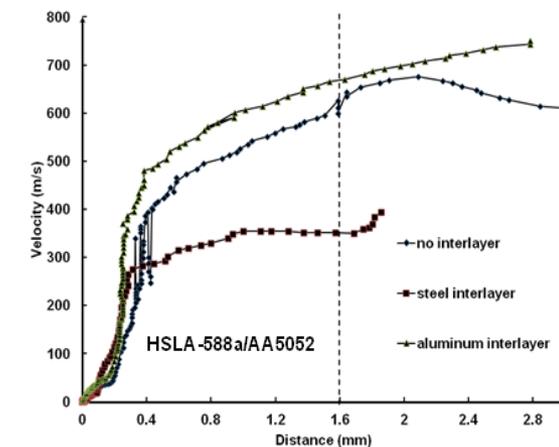
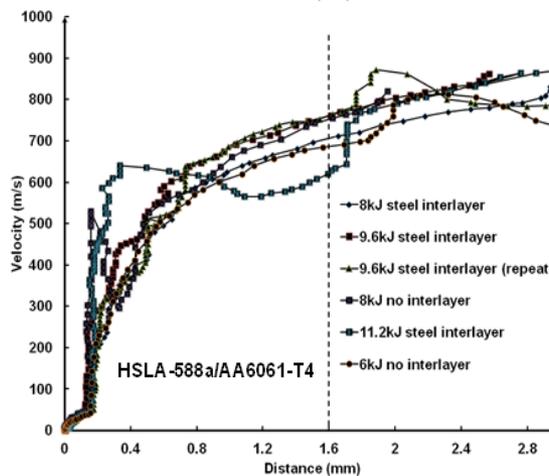
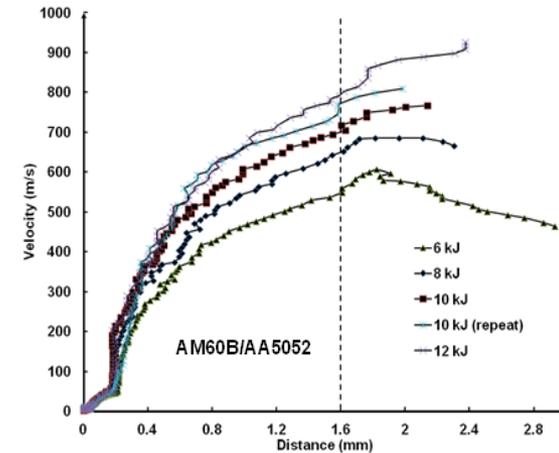
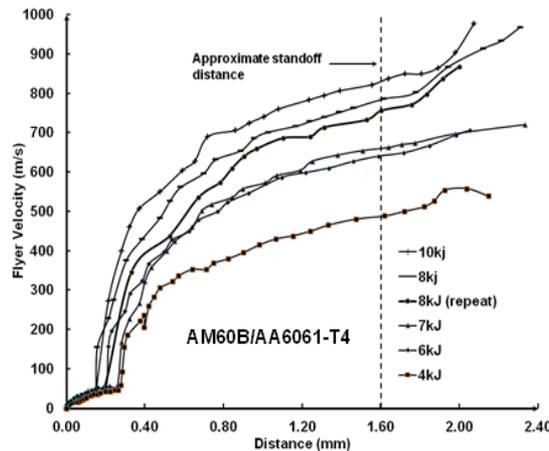
- Peel test data for flat weld samples
- Failure tended to happen in the parent aluminum except for the one weld with 1018 interlayer
- The maximum flyer velocity for each case was found to be
 - No interlayer: 600 m/s
 - AA interlayer: 650 m/s
 - 1018 interlayer: 300 m/s
- Therefore, the data for the 1018 interlayer experiment cannot be trusted



Technical Accomplishments and Progress

A summary of PDV traces from every experiment

- Impact velocity increases with input energy
- For the cases where an experiment at a certain energy level was repeated, the evolution of velocity was generally found to be reproducible



Answers to Reviewers' Comments

- This is our first review. There are no comments yet.

Collaboration and Coordination with Other Institutions

Honda America: Eric Boettcher (Honda R&D, Advanced Design Research), Todd Fitz (Advanced Materials Research Division)

Role: Guidance with material selection and procurement. Will also help with e-coating of welded samples

Alcoa: Mario Greco (Alcoa)

Role: Guidance with material selection and procurement.

Ohio State University, Fontana Corrosion Center: Prof. Rudy Buchheit

Role: Will help with corrosion testing of coated and uncoated welds

Proposed Future Work

- Remainder of FY14:
 - Complete the screening tests
 - During the 3rd quarter, some screening tests will be conducted inside a vacuum chamber to check the presence or absence of a deleterious effect of the air trapped between flyer and grooved target plate.
 - Based on the results of the experiments under vacuum, it will be decided whether or not the target plate should be redesigned. We are considering such experiments where targets with wider, lesser number of grooves, which are widely separated in distance, are used.
- FY15
 - After completion of the screening tests, continuous flat welds will be made for 5 selected combinations under the found optimal conditions of impact angles and velocities
 - Strength-structure relationships would be developed through failure tests
 - Corrosion mitigation strategies would be implemented and tested
 - With our industrial partner we will pursue the commercialization of this process. A dissimilar welding project with Johnson Controls, Inc. is underway.

Technical Summary

- Vaporizing foil actuator welding (VFAW) offers a possible tool for welding dissimilar metals together
- Screening tests on the 4 combinations tested till date have yielded mixed results: welding to grooved targets made from magnesium alloy AM60B has proven successful under certain conditions, whereas, direct welding of aluminum flyers to grooved HSLA (588a) was not possible
- Couple of strategies have been successfully implemented to counter the possible reasons for non-bonding or rebound after welding: (i) use of interlayers, (ii) use of flat target plates, (iii) entrapped air will be treated with a vacuum enclosure.
- Screening tests of 11 more combinations would be completed during the remainder of FY14 and prototype build with downselected 5 combinations would be done during FY15. Detailed characterization of the welds along with testing of corrosion mitigation strategies would also be done in FY15