Welding and other applications of the Vaporizing Foil Actuator (VFA) tool

2nd December 2016, Nantes, France

Anupam Vivek, Glenn Daehn

Geoff Taber, Bert Liu, Steve Hansen, Ryan Brune, Brian Thurston, Yu Mao, Alex Koenig, Scott Wright, Taeseon Lee, Ali Nassiri, Angshuman Kapil, Bhuvi Nirudhoddi

iml.osu.edu

THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING

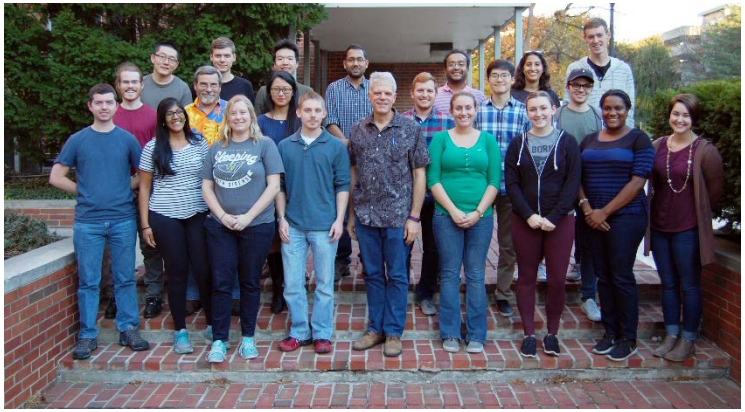
Outline

- Impulse manufacturing lab
- Impact welding (Vaporizing Foil Actuator Welding)
- Other applications
  - Cutting
  - Shape calibration

Impulse Manufacturing Lab

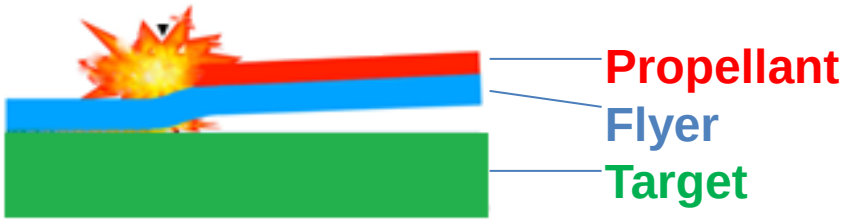
- Moving materials at strain rates > 1000/s
- Speeds > 100 m/s
- By electromagnetic induction, laser ablation and vaporizing foil actuator
- Weld, form and cut materials, mostly metals
- 5 capacitor banks: 1 kJ to 48 kJ
- 3 PDVs measuring velocities from 1 m/s to 2 km/s on up to 16 channels

iml.osu.edu



Impact welding

- Solid-state welding by means of a high-speed, oblique impact.
  - Critical parameters
    - Speed: typically about 300~1000 m/s
    - Angle: typically about 5°~30° (must be > 0°)
  - Traditionally done by using explosives and later, magnetic pulse



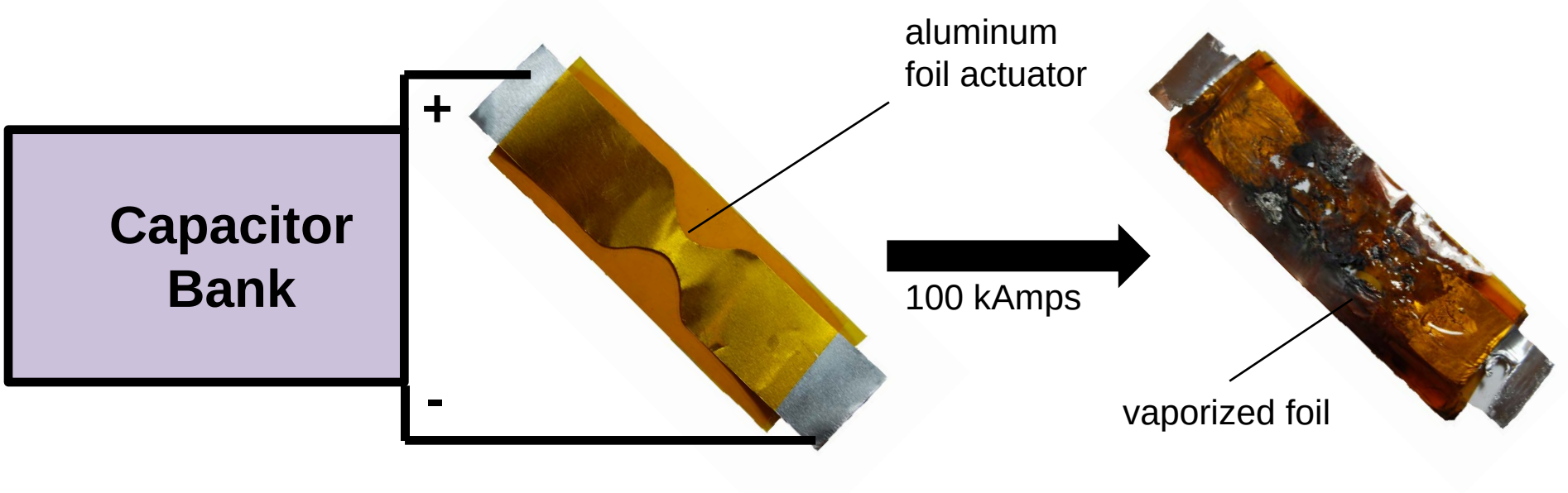
http://en.wikipedia.org/wiki/Explosion_welding (modified)

http://sections.aws.org/johnstown/photos.htm

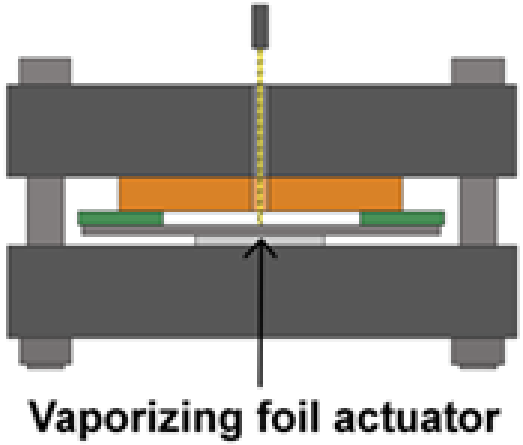
Cons: Explosive! Actuator longevity!

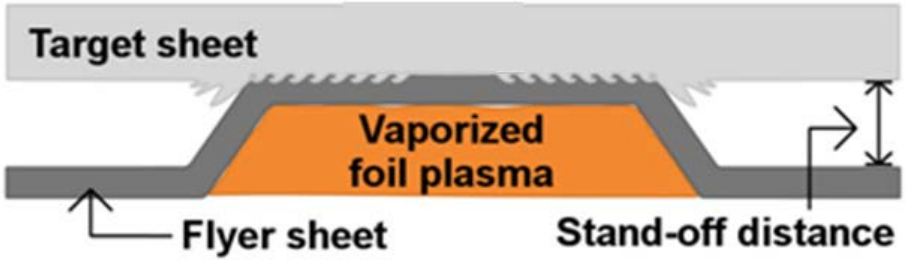
Vaporizing Foil Actuator Welding

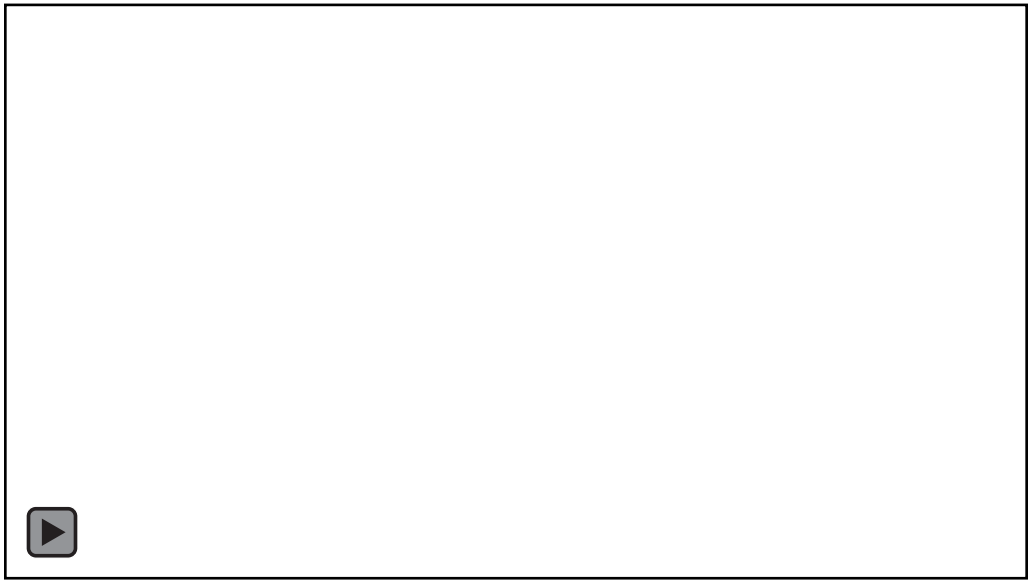
NOT MPW



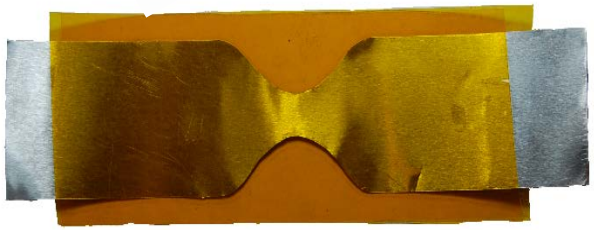
Welding Procedure

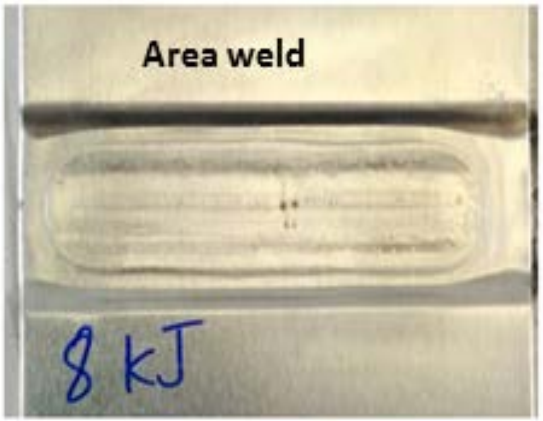




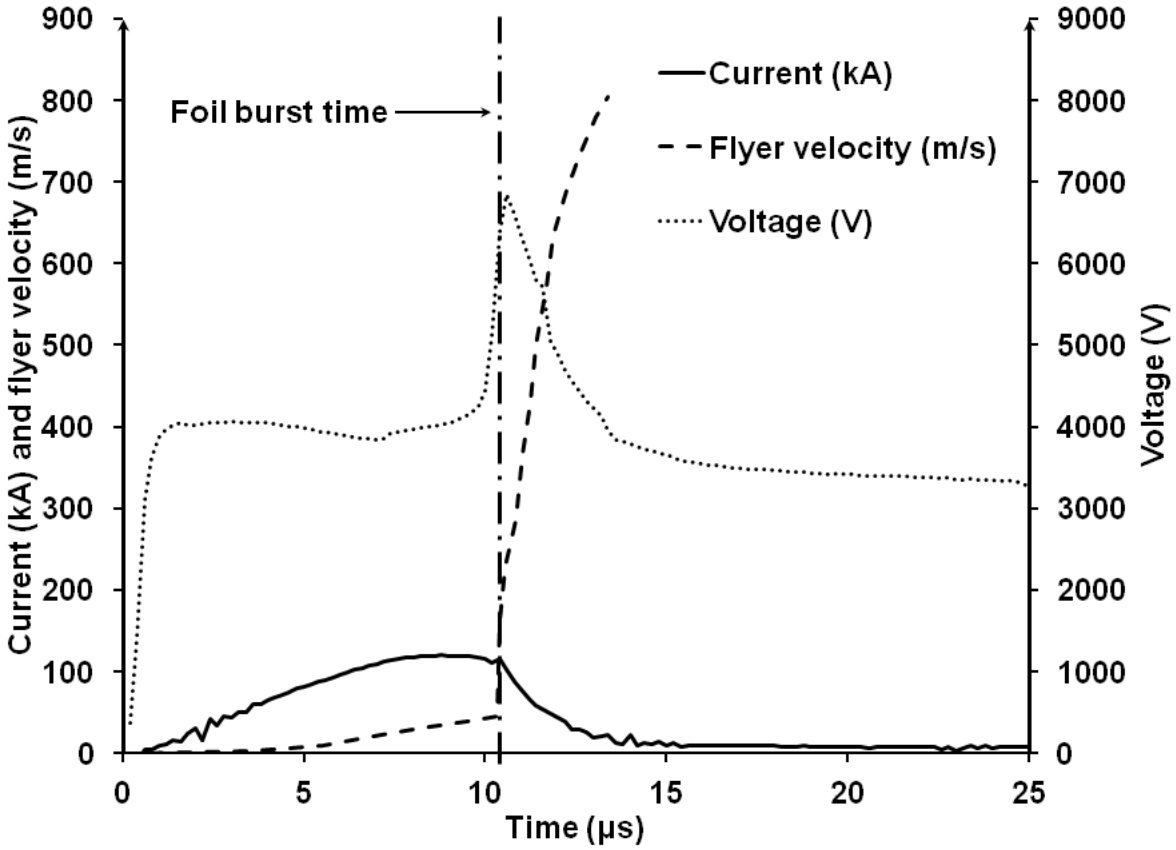


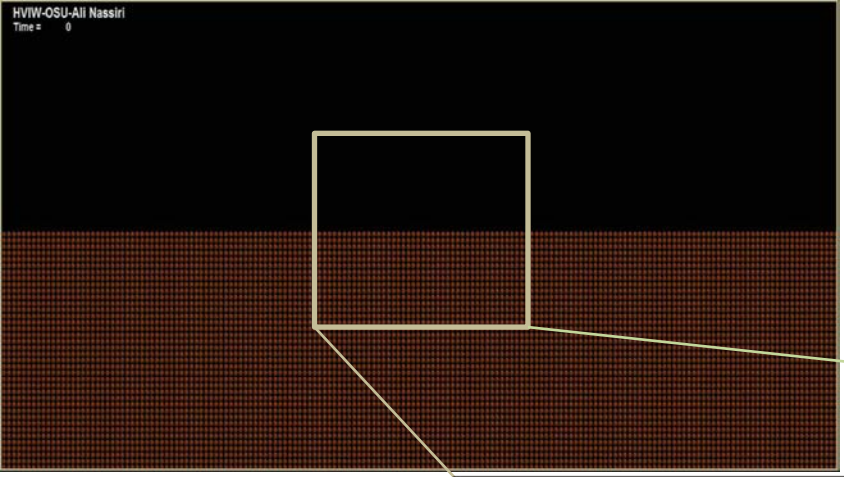
VFAW shapes





Current, Voltage and Velocity

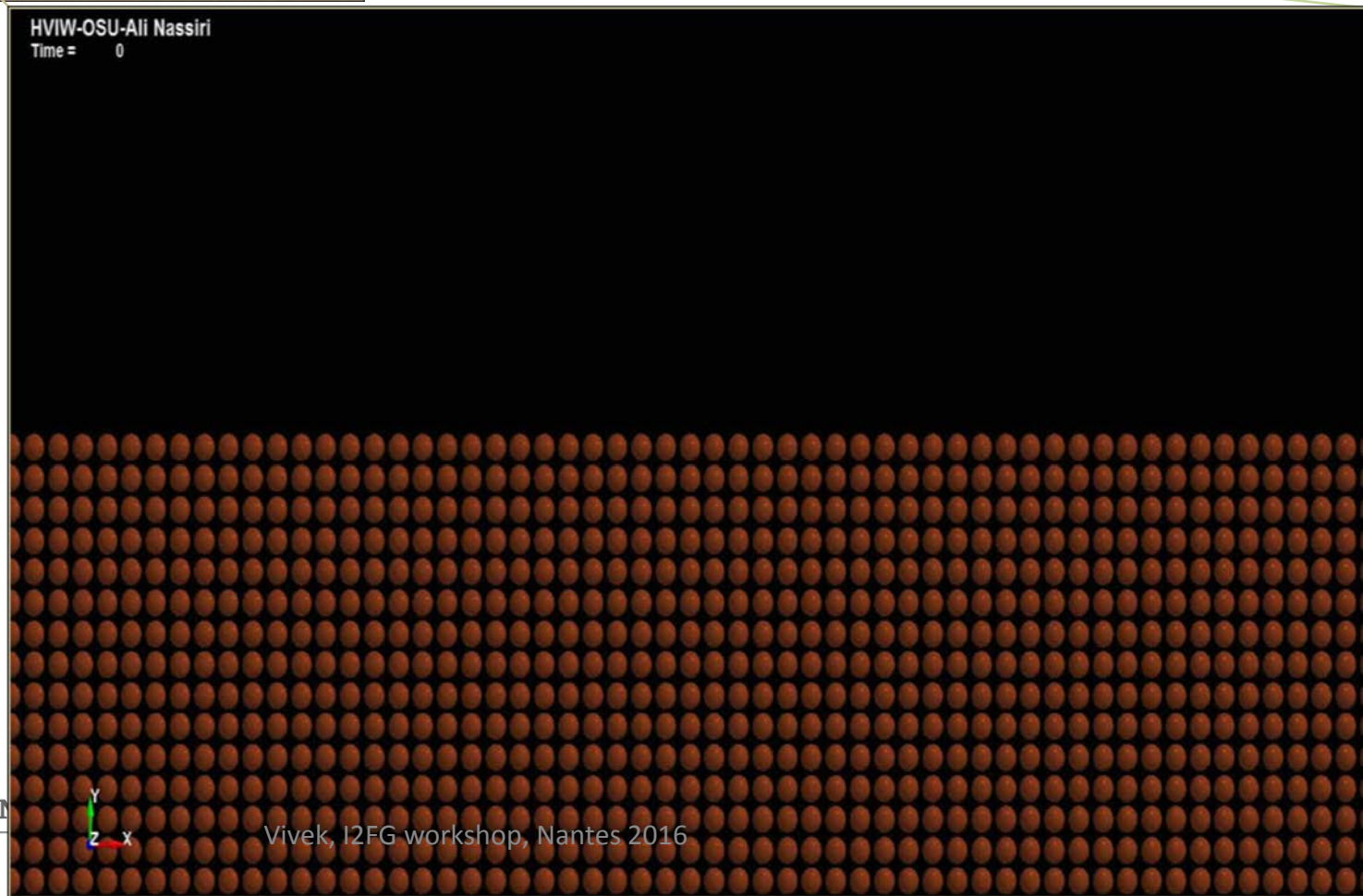




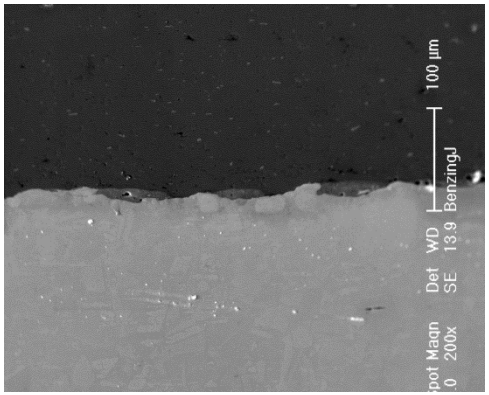
High Velocity Impact Welding of CP-Ti/Cu 110

Impact Velocity: 770m/s

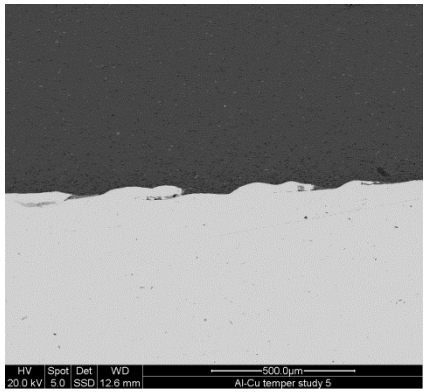
Impact Angle: 24°



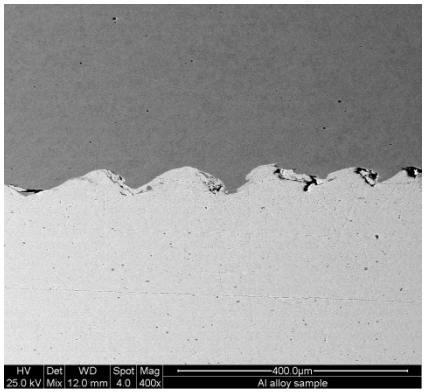
VFAW combinations



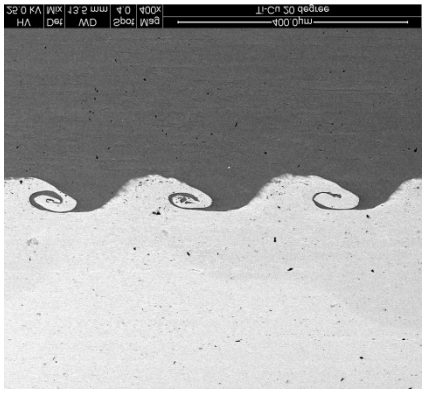
AA6061-SS304



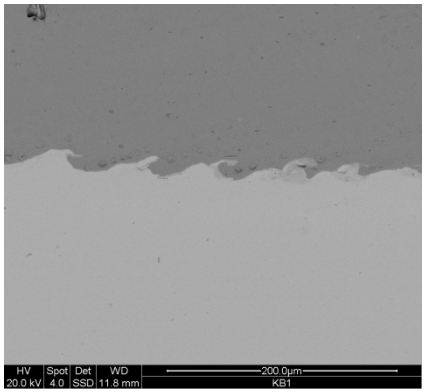
AA6061-Cu



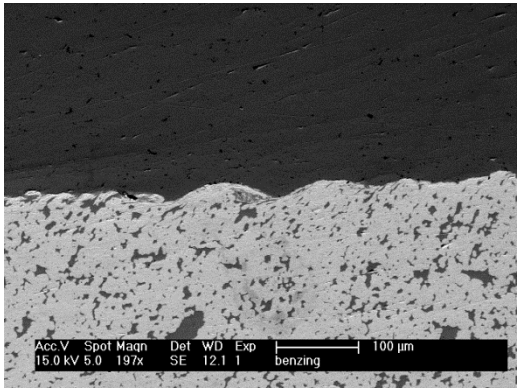
Cu-1018 steel



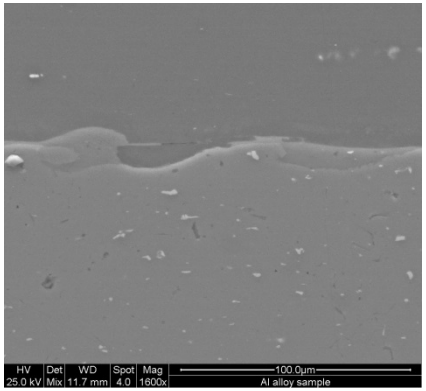
Cu-CP Ti



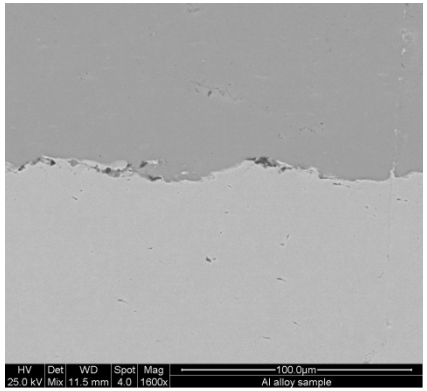
Cu- Zr BMG



Cu-17F W alloy



AA6061-AZ91D



CP Ti-1018 steel

and a few more…

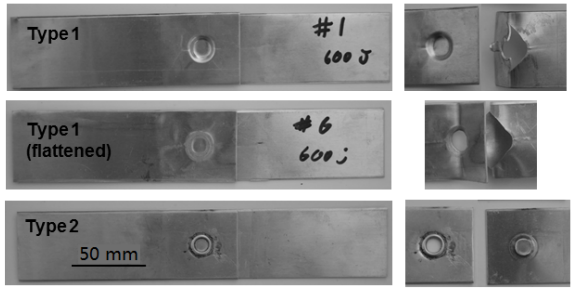
VFAW-ed combinations

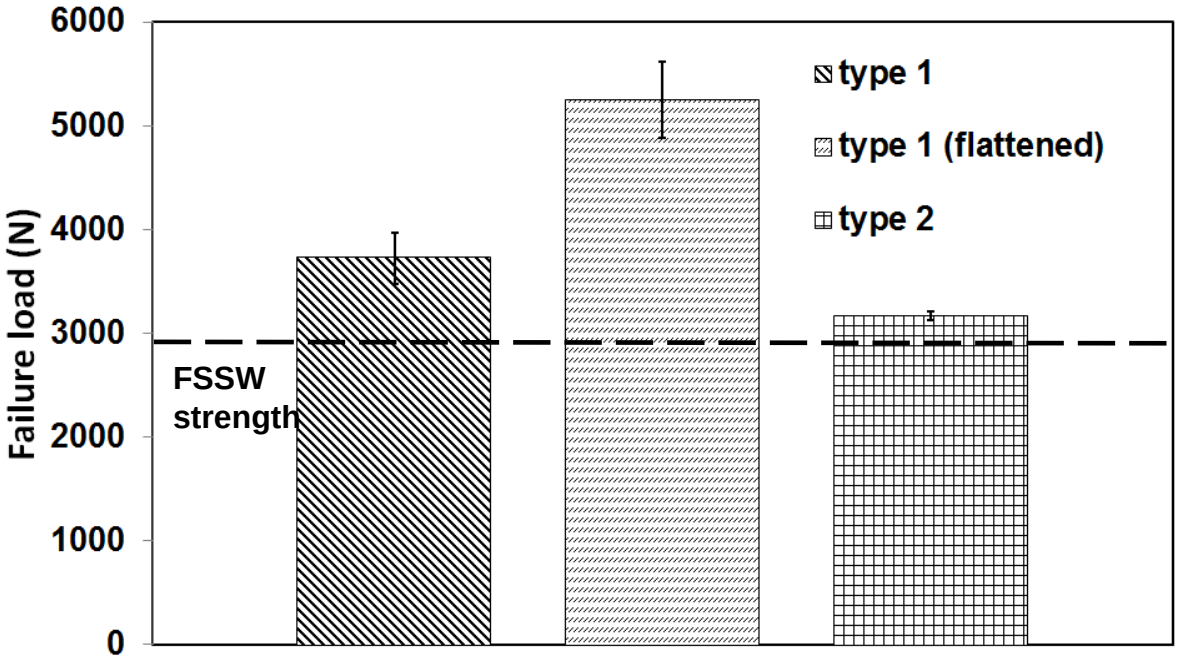
Target / Flyer	1xxx	2xxx	5xxx	6xxx	7xxx	Aural 2	A356	AISI 1018	DDQ stainless steel	DP 590	DP 780	DP 980	Usibor 1500	Cu 110	CP Ti	Magnesium AM60B
1xxx	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊	😊
2xxx	😊	😊												😐		
5xxx	😊		😊	😊	😊	😊	😐	😐	😊	😊		😊	😊			😐
6xxx	😊		😊	😊	😊	😊	😐	😐		😊	😊	😐	😐	😊	😊	😐
7xxx					😊					☹		☹	☹			
Aural 2								😐								
A356					😐				😊							

Peel strength > 250 N/mm

5052-H32 welds: Comparison to FSSW

Lap shear tests



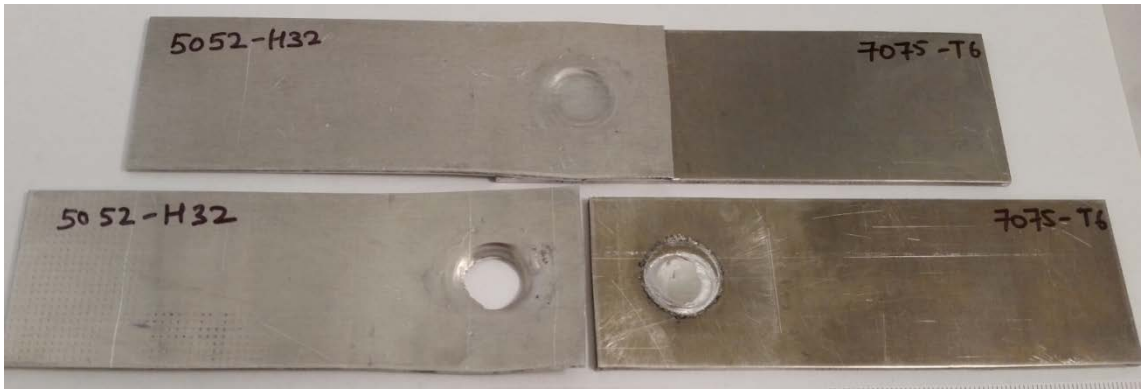


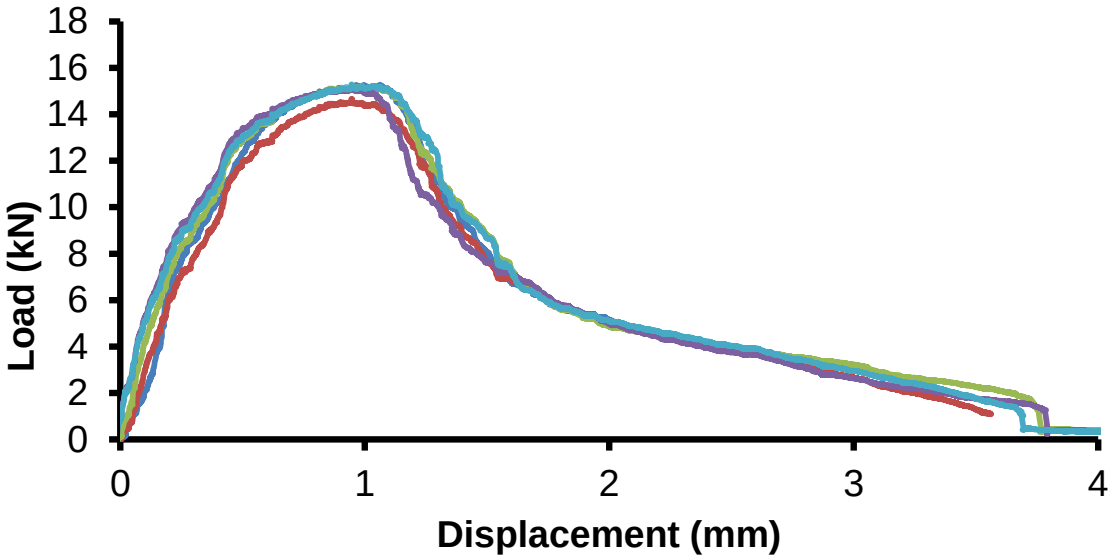
All welds created with 600 J

Zhang, Z., Yang, X., Zhang, J., Zhou, G., Xu, X., Zou, B., 2011. Effect of welding parameters on microstructure and mechanical properties of friction stir spot welded 5052 aluminum alloy. Materials and Design, 32(8-9), 4461–4470. doi:10.1016/j.matdes.2011.03.058

AA5052/AA7075 results: Mechanical Tests

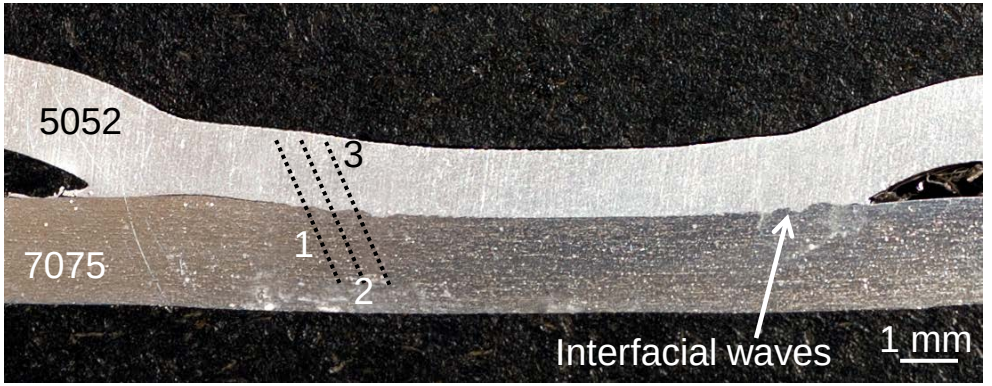
- 5052 thickness: 2 mm
- 7075 thickness: 2.3 mm
- Input energy: 4 kiloJoules
- Impact velocity: 580 m/s
- Spot size: 15 mm
- Samples left a nugget

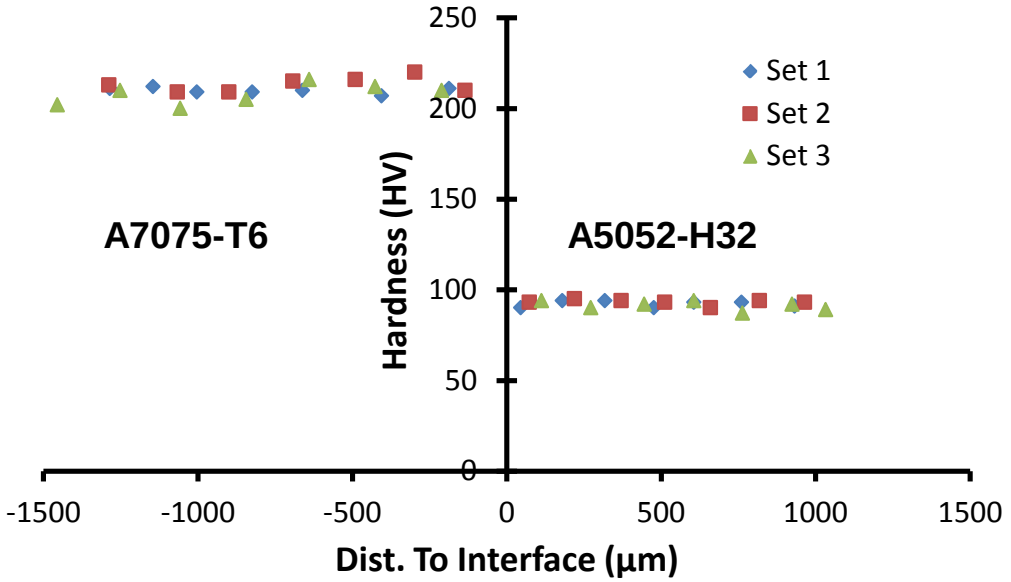




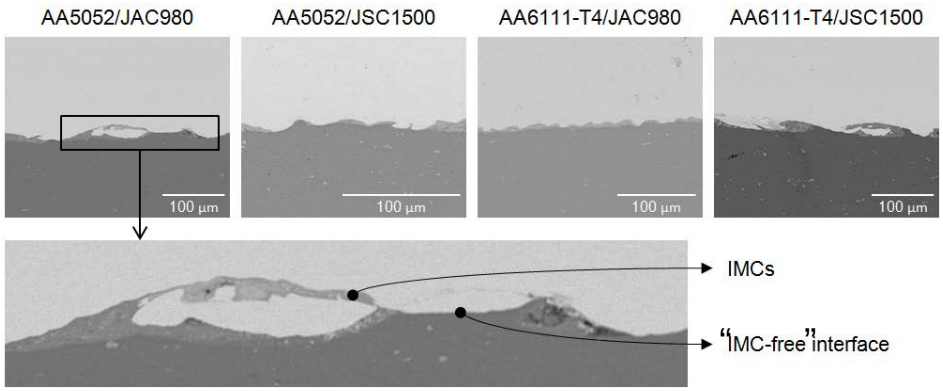
AA5052/AA7075 results: Microanalysis

- Strength of base material retained
- Negligible thinning
- Wavy interface

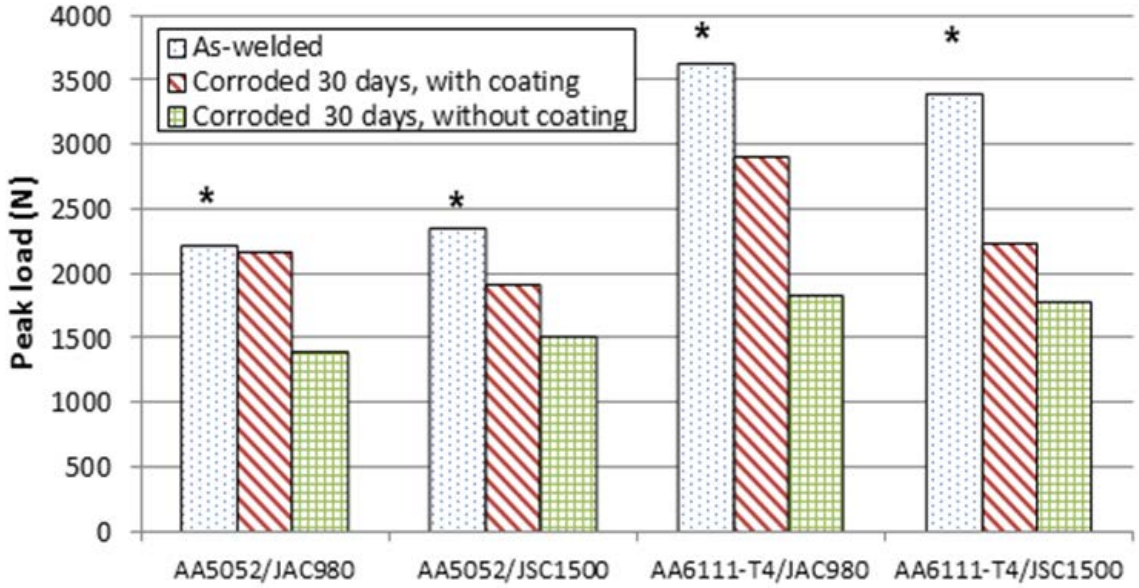




Aluminum-steel welding



(a)



(b)

Present: Pedestal system

<100 decibels, 20 second cycle time

Current Collaborations on VFAW

- **OEM:** Honda, others
- **Tier 1:** Magna, Jefferson Industries
- **Equipment builder:** Coldwater Machine
- **Materials:** Alcoa, Meridian, Ashland
- **Modeling:** UNH, OSU SIM Center, PNNL
- **Training:** Tri-Rivers Center

Collaborators:
Tim Abke (Honda)
Duane Detwiler (Honda)
Pete Edwards (Honda)
JK Hong (Battelle)
Marc Auger (Magna)
Michael Barker (Ashland)
Matt Brienzo (JIC)
Dan Bryant (Alcoa)
Jen Locke (OSU)
Jason Johnson (OSU)
Erman Tekkaya (TU)
Tim Abke (Honda)
Christian Weddeling (TU)
Marlon Hahn (TU)
Anthony Luscher (OSU)
Suresh Babu (UTK)
Curtis Prothe (DMC)
Brad Kinsey (UNH)
Xin Sun (PNNL)
….and many others

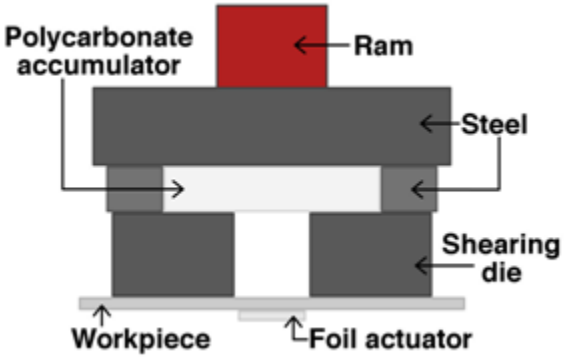
Other applications

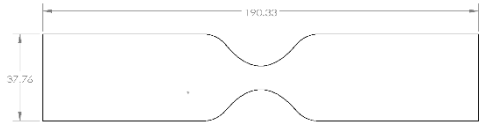
- Forming
- Cutting
- Shape calibration
- Conformal/Interference fits

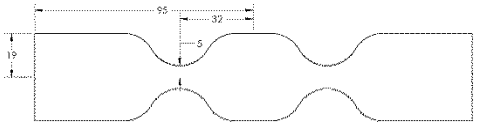
Other applications

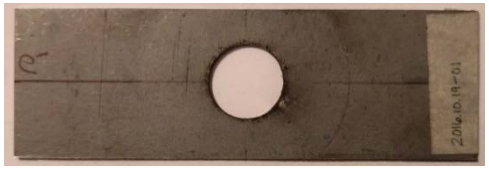
- Forming
- **Cutting**
- **Shape calibration**
- Conformal/Interference fits

22MnB5 shearing using VFA

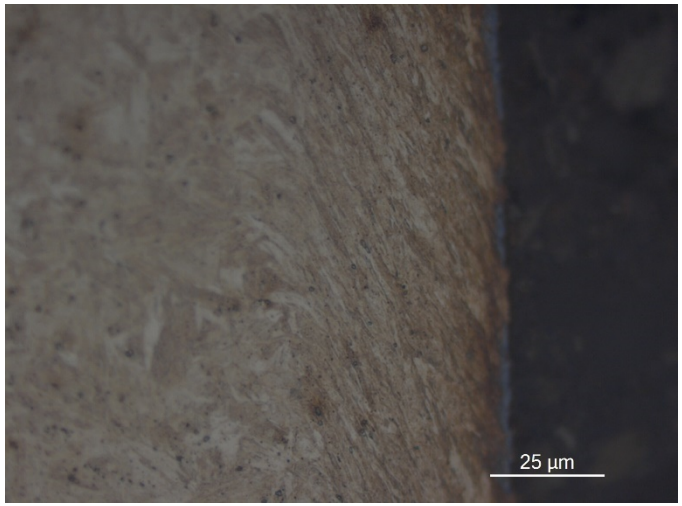


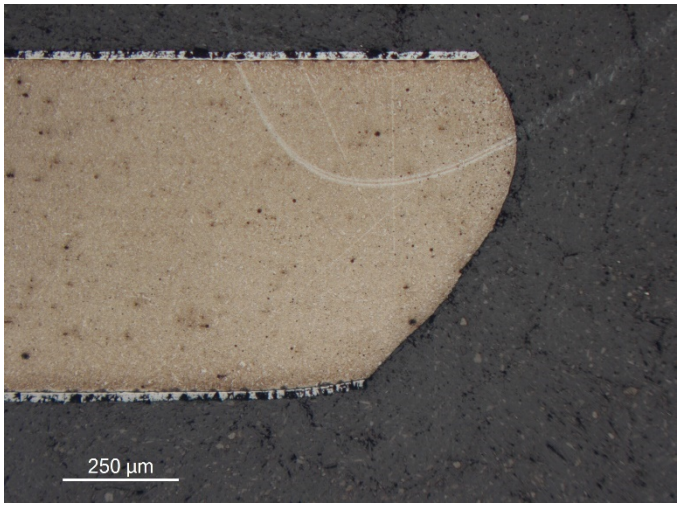






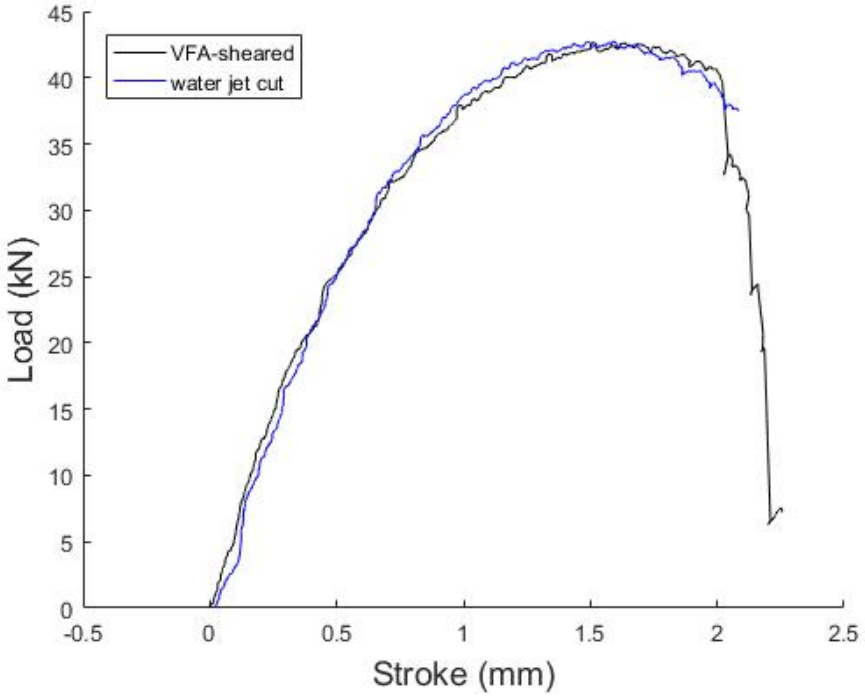
1.5 mm thick 1500 MPa boron steel





22MnB5 shearing using VFA

- Uniaxial tension



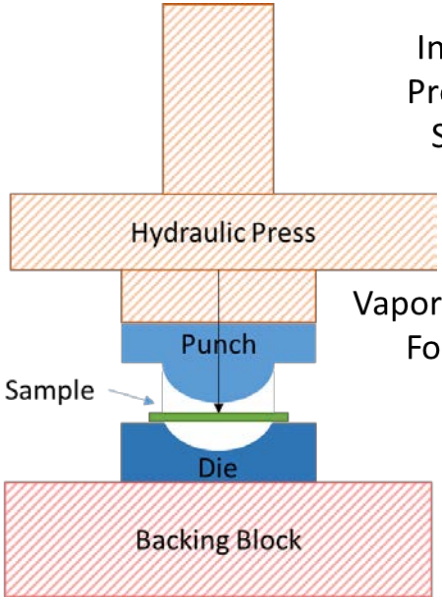
- Low-cycle fatigue
  - 10 Hz, 50% ultimate failure load

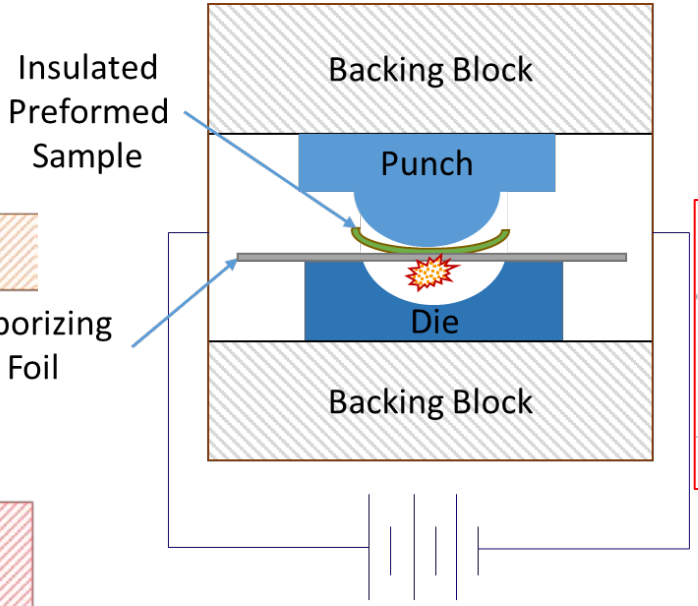
Cutting method	Cycles to failure
VFA shear	4219
Water jet	6131

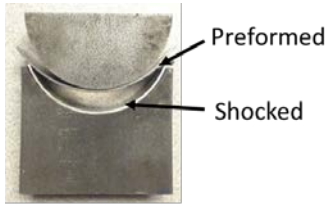
VFA Shape Calibration Process

1. Pre-form as received sample to target shape using a hydraulic press

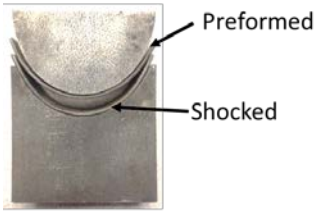
2. Calibrate using Vaporizing Foil Actuator Method



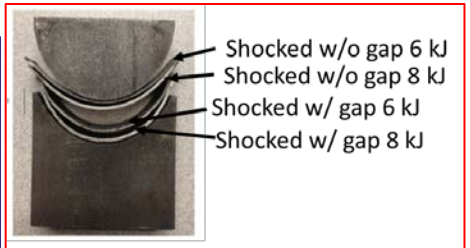




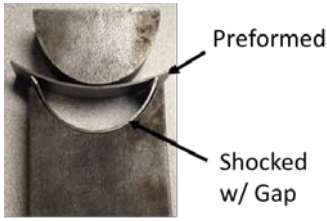
Al - 6061



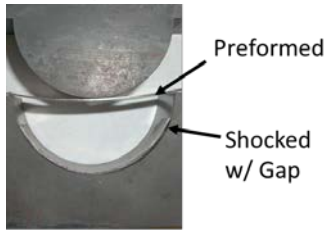
Steel - 590



Ti - 64



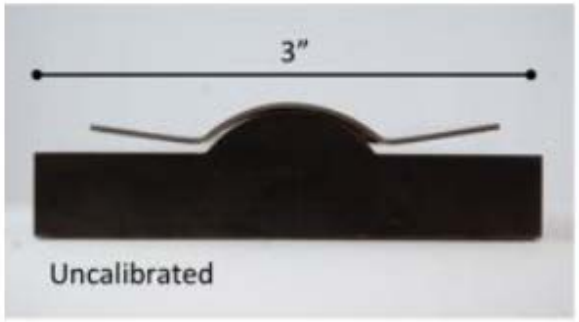
Ti - 64



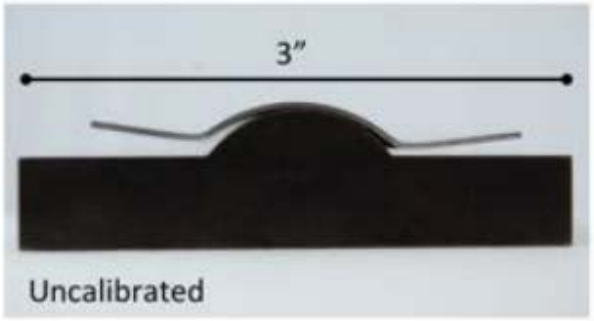
Ti - 6242

More calibrated shapes

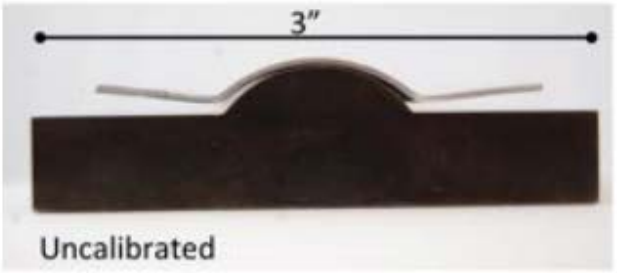
Titanium



DP 980 Steel



T6 6061 Al



Study of Springback Relief Mechanism

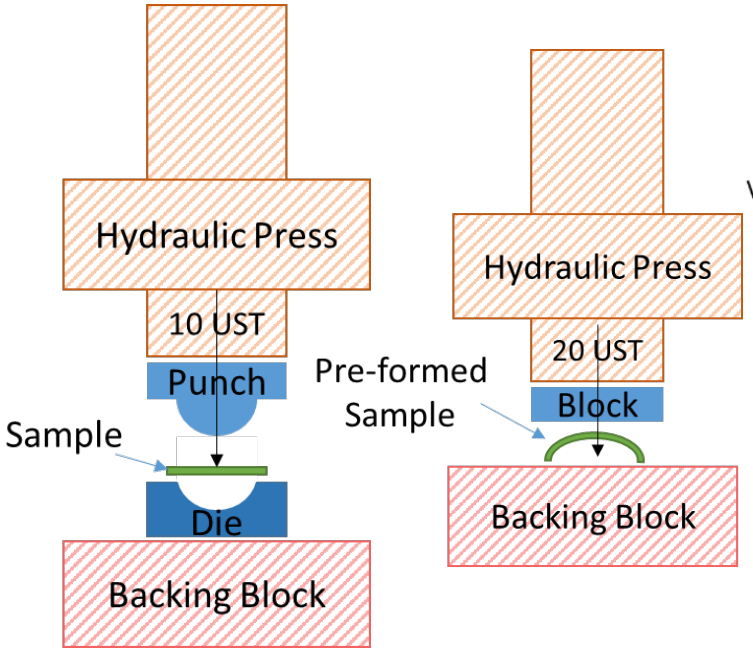
1. Pre-form as received sample to a semicircular shape using a hydraulic press. Tonnage = 10 US tons

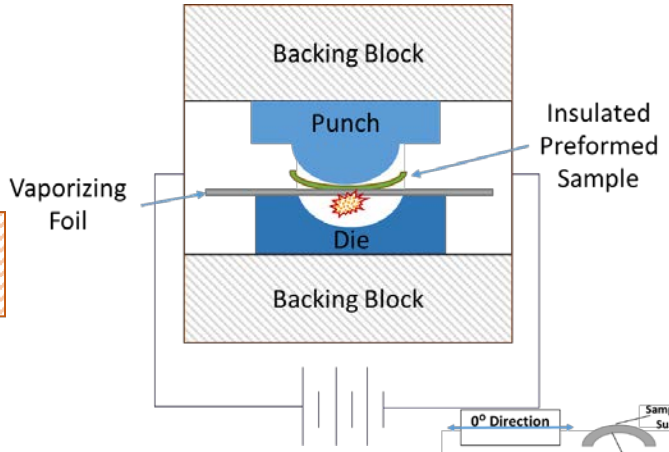
2. Flatten the pre-formed sample using a hydraulic press. Tonnage = 20 US tons

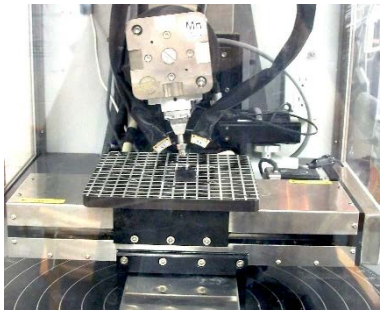
3. Recalibrate/Flatten using VFA, at 3 energy levels:

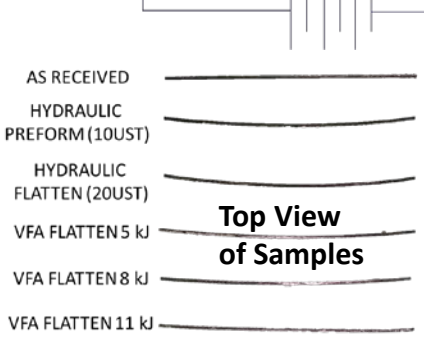
   5 kJ, 8 kJ, 11 kJ

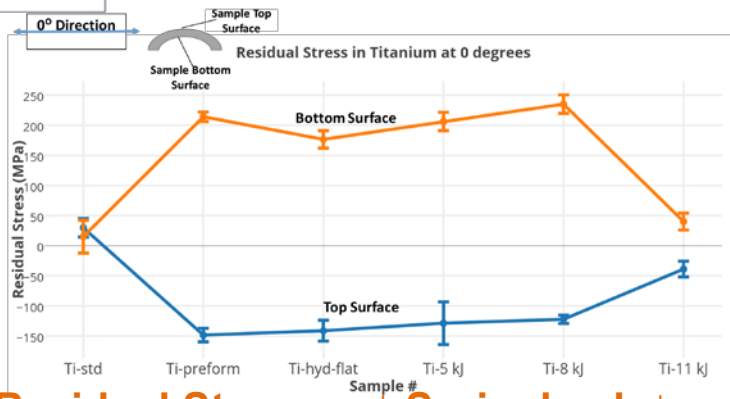
4. Measure Residual Stresses at different stages using Laser XRD









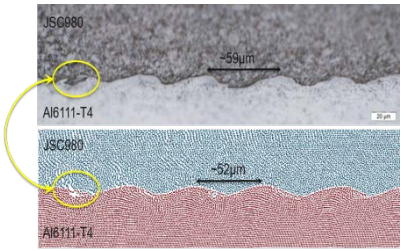


VFA/Shock Energy ↑Residual Stresses ↓ Springback ↓

Key takeaways

- ✓ Similar and dissimilar combinations
- ✓6mm thick aluminum
- ✓Flange width 10mm with aluminum
- ✓Aluminum welding: reliable

- ✓Current status: Pedestal system
- ✓well-supported by state, federal and industry projects
- ✓Key strategic partners engaging
- ✓ SPH-based simulations



- ✓ Also useful for springback removal and cutting of high strength materials

HONDA

TARDEC

MAGNA

Ohio Development Services Agency

NSF

COLDWATER MACHINE COMPANY

ASHLAND

JIC

ALCOA

MY FUTURE. MY CHOICE. TRI-RIVERS CAREER CENTER

Questions

- Anupam Vivek: vivek.4@osu.edu Glenn Daehn: daehn.1@osu.edu

- Impulse Manufacturing Lab: iml.osu.edu