Impact Welding in a Variety of Geometric Configurations

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Outline

- Introduction of Impact Welding
- Motivation and Objective
- Different Configurations for MPW
- Process Parameter Measurement
- Joint Property and Microstructure Study
- Conclusion
- Acknowledgement

Roadmap

Configuration
- Plate to Plate Lap Joint
- Flanging and Welding
- Tube to Rod Lap Joint

Process
- Primary Current-Rogoswki
- Impact Velocity-PDV
- Impact Angle-Multiple PDV

Property
- Lap Shear Test
- Peeling Test
- Microhardness Test
- Nanoindentation Test

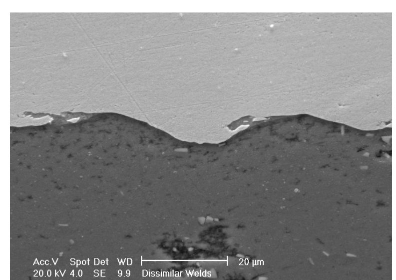
Multi-scale Characterization

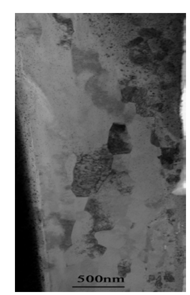
SEM

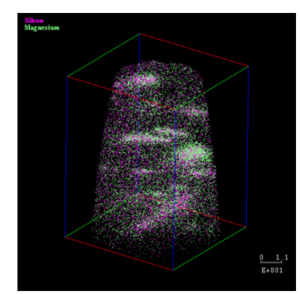
FIB

TEM

3DAP







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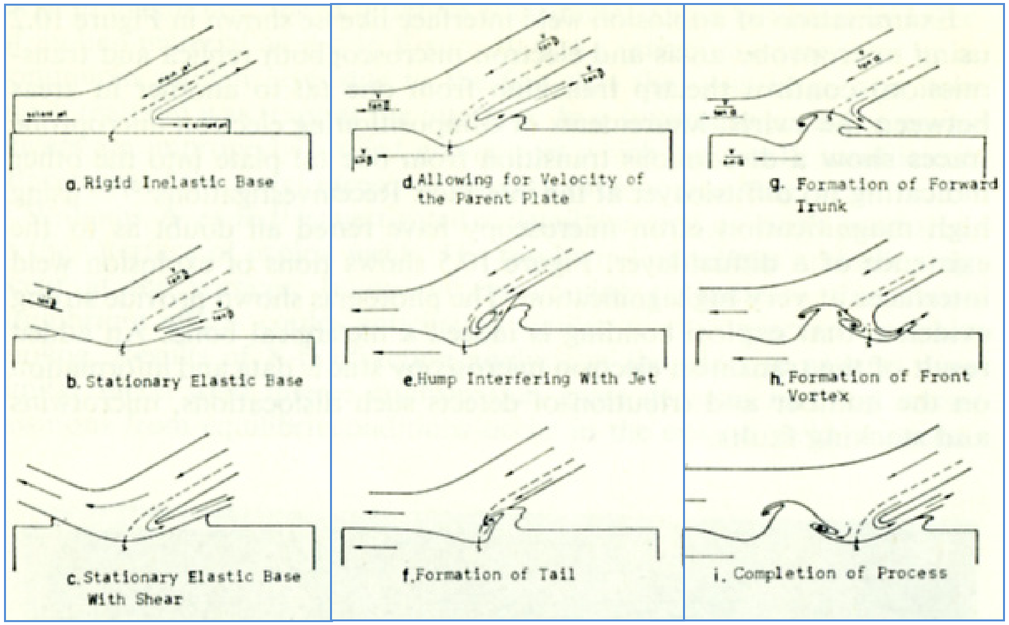
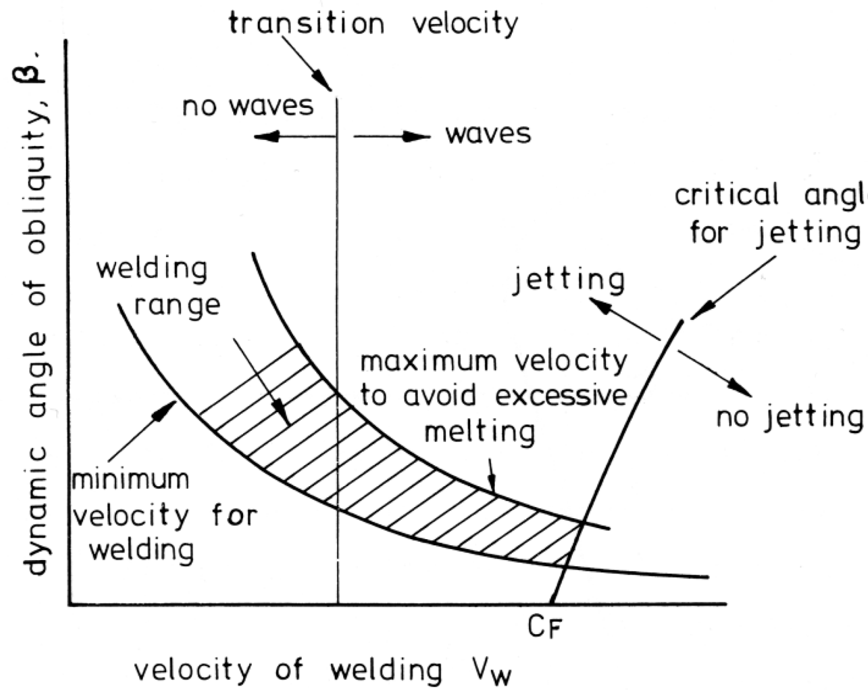
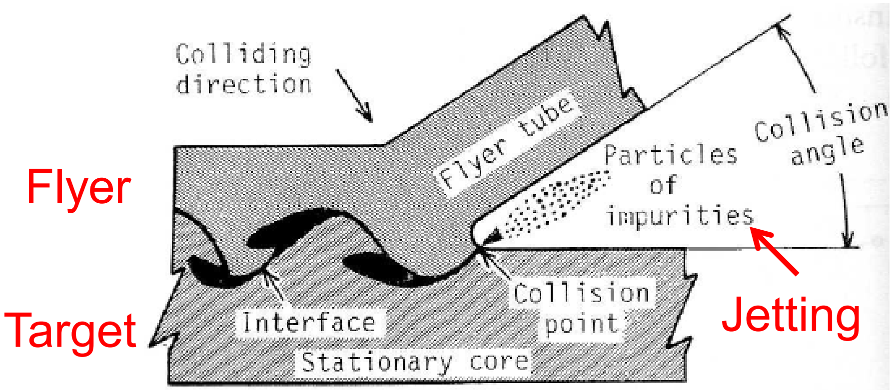
Impact Welding Mechanism



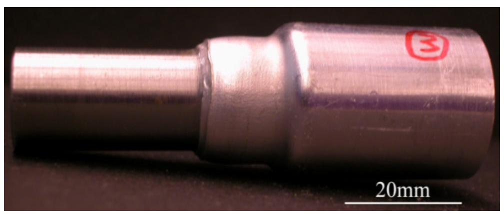




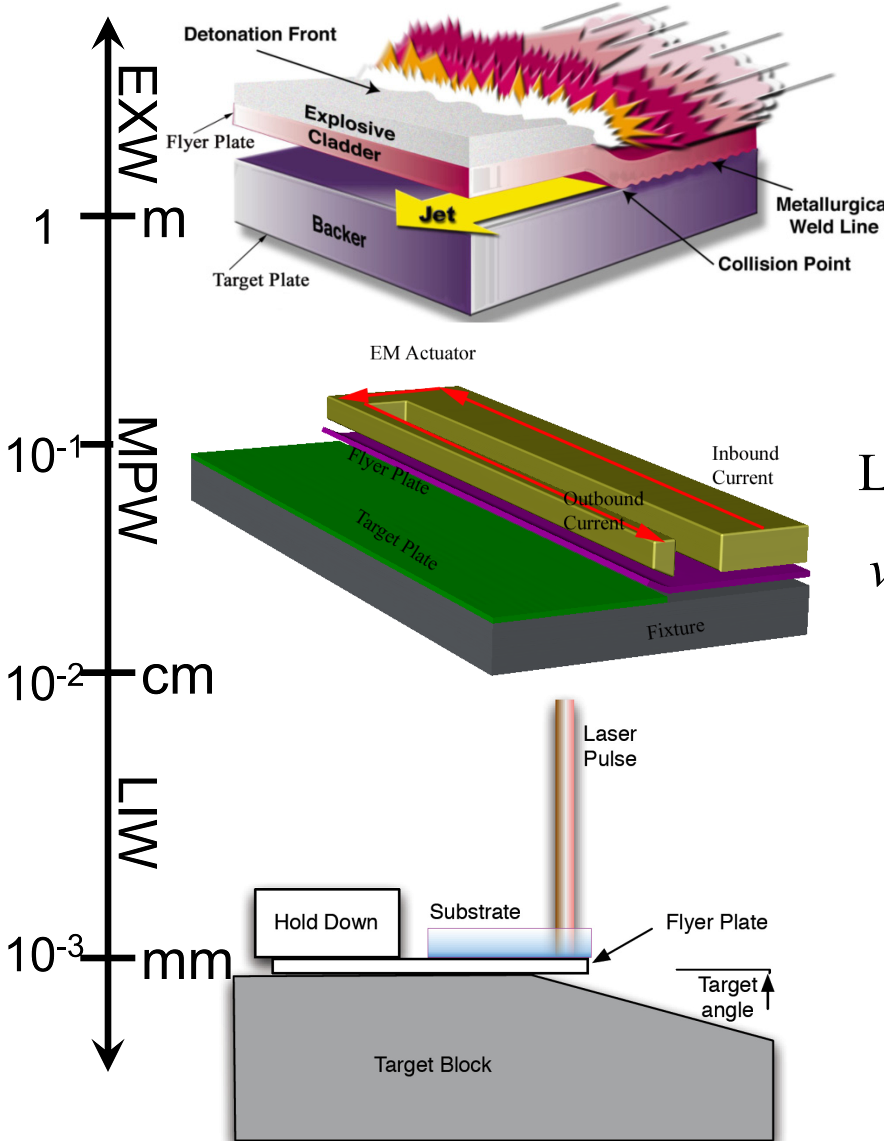
- Form material jet at collision point
- Remove oxide from metal surface
- Allow atoms approach to inter-atomic distances
- Form metallic bonding on contact
- Require impact angle and velocity

[Isao Masumoto et.al. 1985; Bahrani A.S. et. al.1967; Ezra A.A.,1973]

Different Impact Welding Systems*



Diameter for a quarter is ~24mm.



Widely applied

v_{Impact} ~1000m/s

Limited application

v_{Impact} 200~500m/s

Raised recently**

v_{Impact} ~475m/s

*[*Y. Zhang et.al., 2010; **G. Daehn and John Lippold, 2009]*

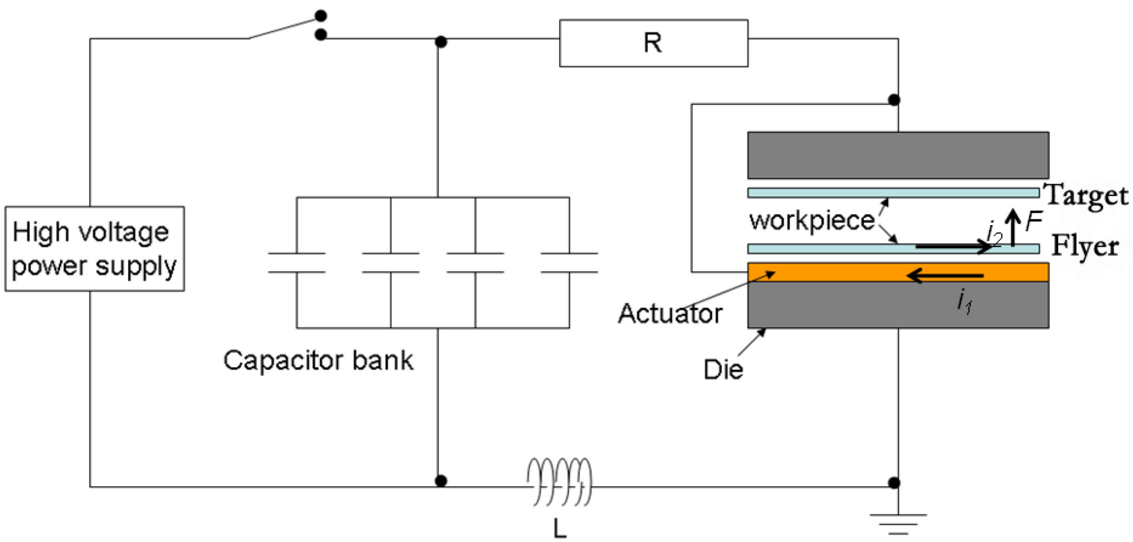
Motivation and Challenge

- Motivation
  - No significant heat affected zone (HAZ)
  - Able to bond both similar and dissimilar materials
  - Joint having greater strength than base metals
  - Fast welding process
  - Flexible to weld geometry
  - High reliability/reproducibility

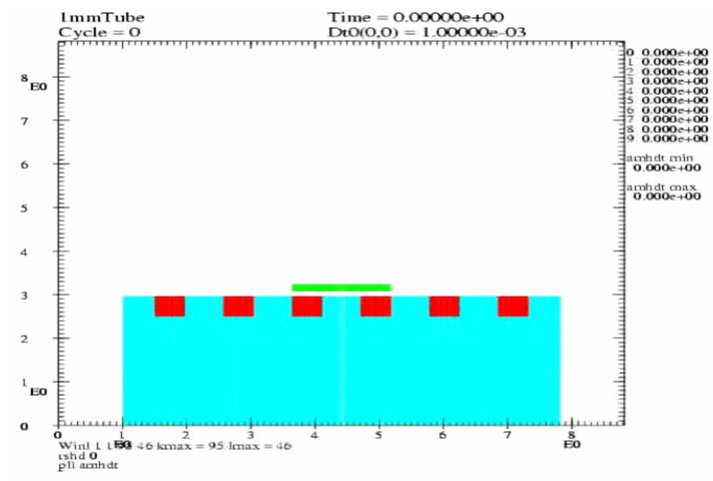
- Objective:
  - Weld dissimilar materials
  - Apply impact welding for smaller length scale
  - Use impact welding to typical manufacturing environment

MPW Principle

- Primary electromagnetic (EM) field in actuator induces secondary EM field inside of nearby metal workpiece (flyer plate).
- Primary and secondary EM fields are parallel but in opposite direction.
- Repelling force accelerates flyer plate colliding against stationary target plate to make lap joint in high impact velocity.



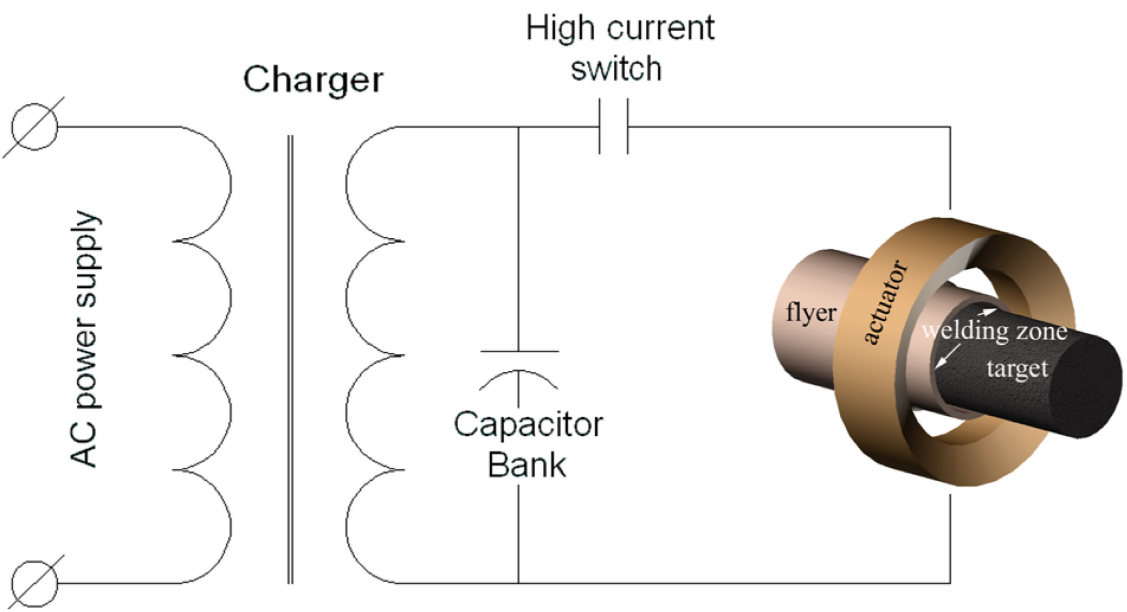
Schematic Illustration



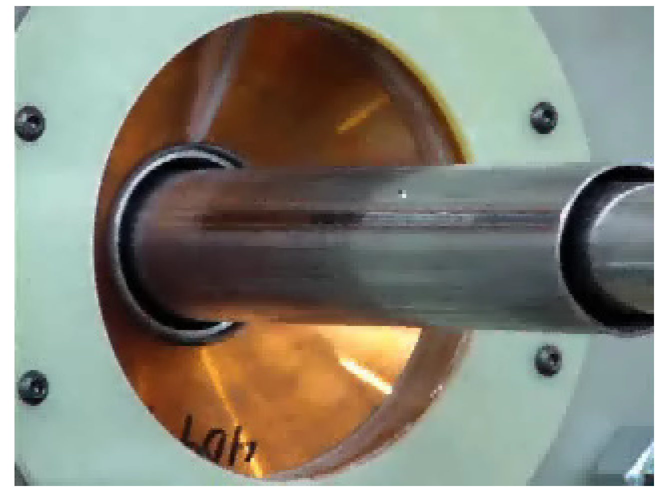
Flux Line for Electromagnetic Field*

[*Courtesy to Gregg K. Fenton, TMS 2008]

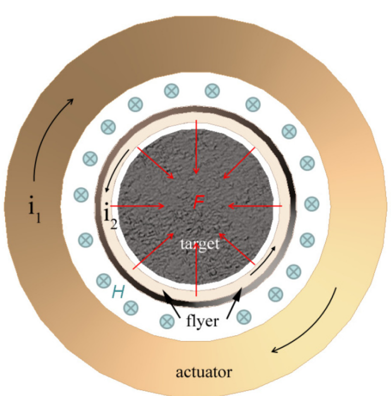
Circular Actuator for Axis Symmetrical Welding

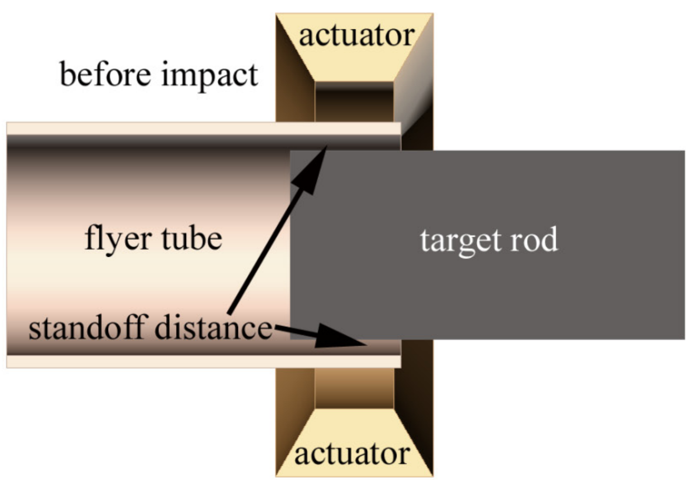


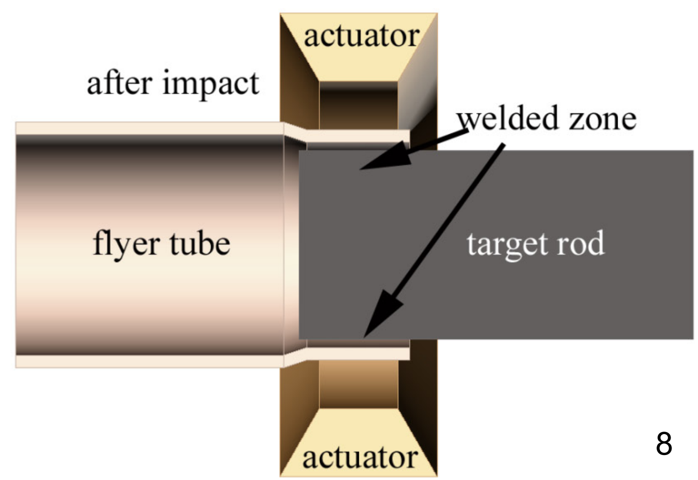
Schematic Illustration



Experimental Setup

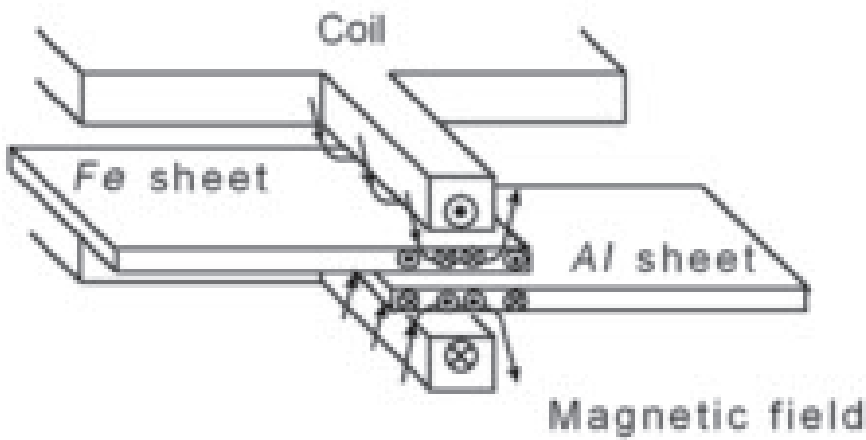




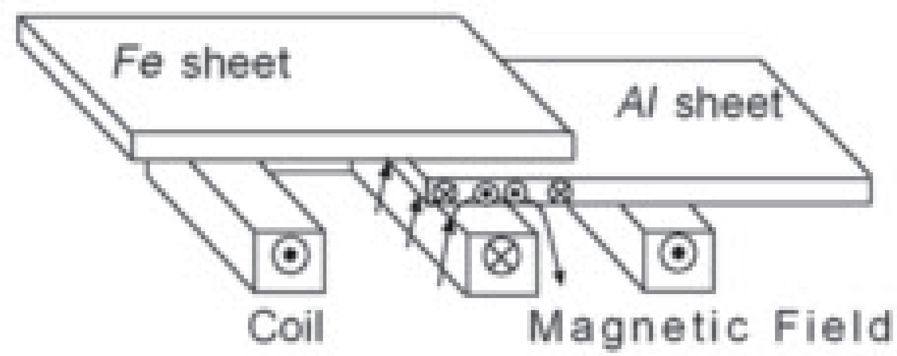


Bar Actuator for Plate-to-Plate Welding

Literature Research



Double layer, H-shaped flat coil*

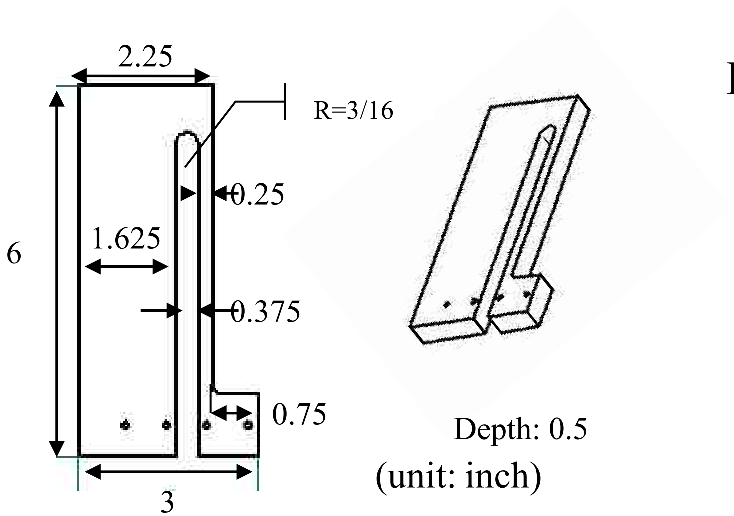


One layer, E-shaped flat coil*

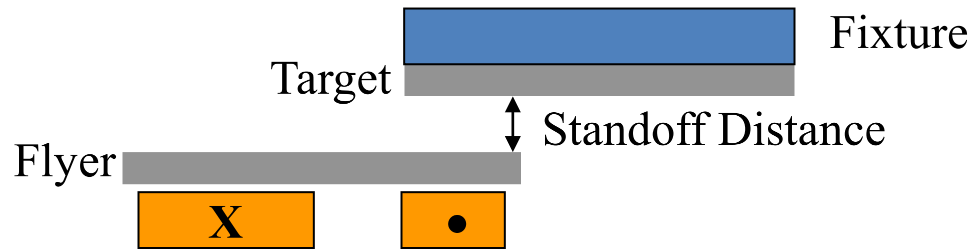
[T. Aizawa, M. Kashani, and K.Okagawa, welding Journal 2007, Vol. 86]

Bar Actuator for Plate-to-Plate Welding

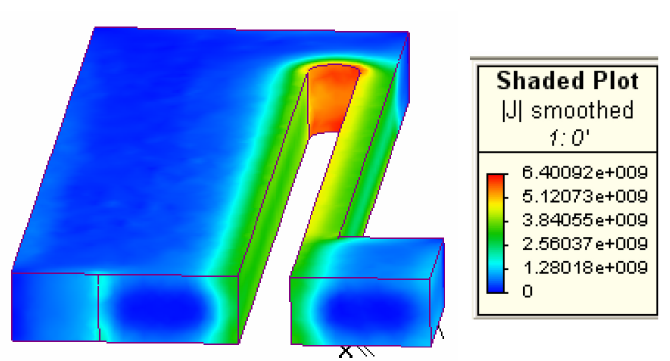
1st Generation



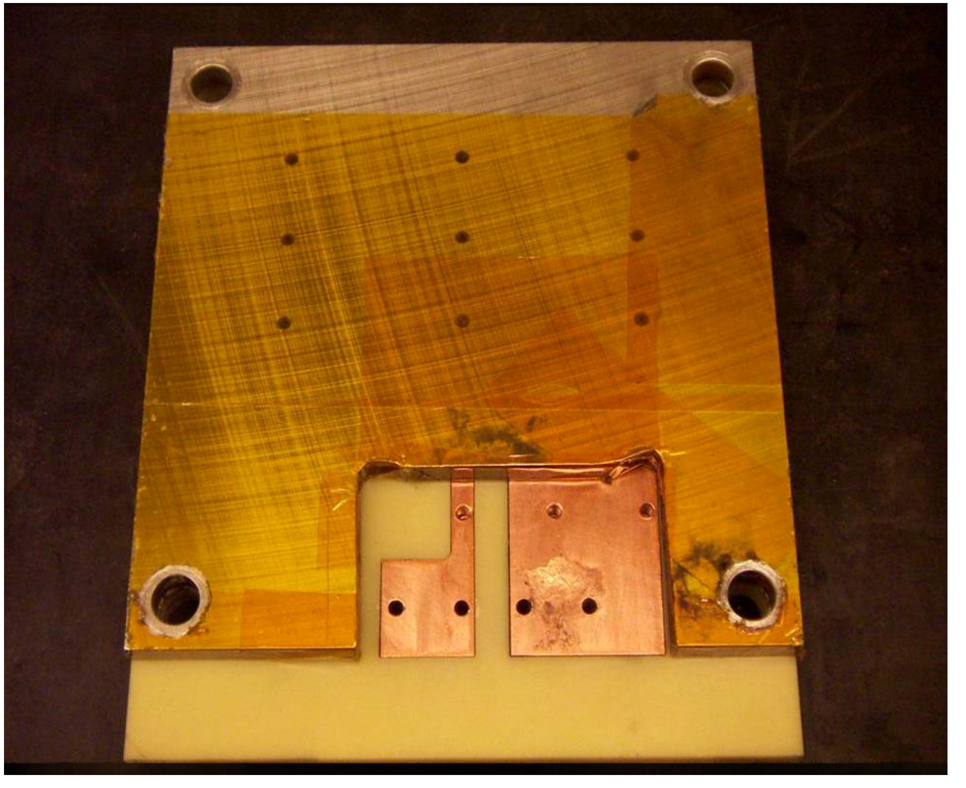
CAD Design



Schematic Illustration



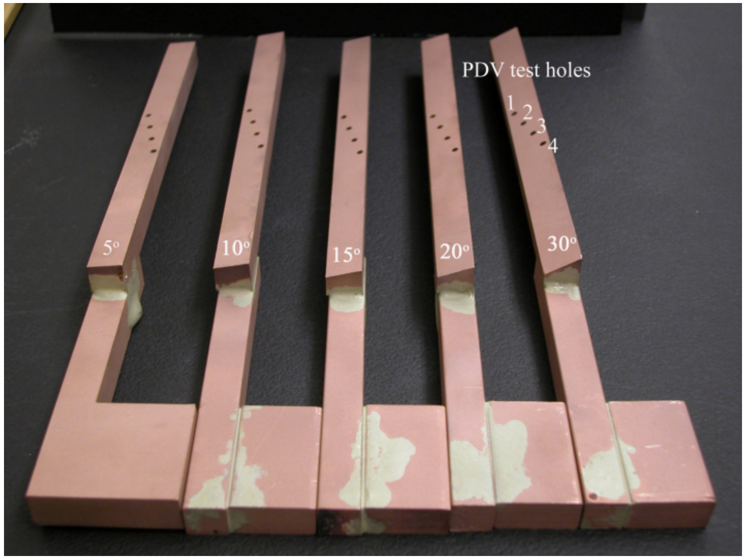
Magnet® Simulated Current Density



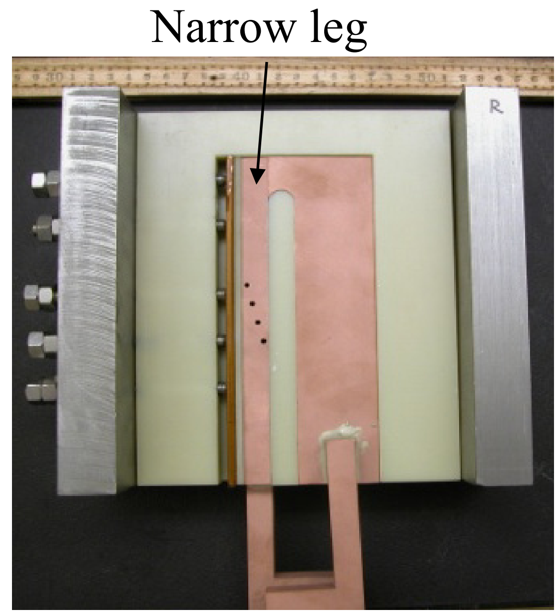
Fixture Die with Insulator Tape

Bar Actuator for Plate-to-Plate Welding

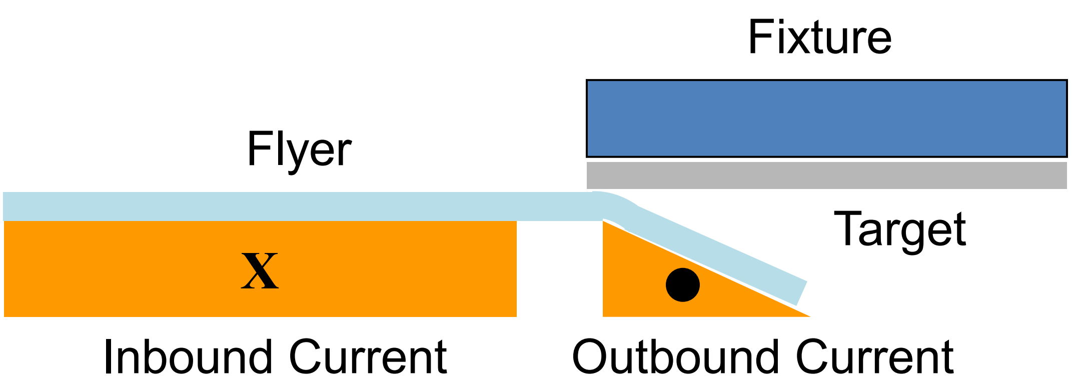
2nd Generation



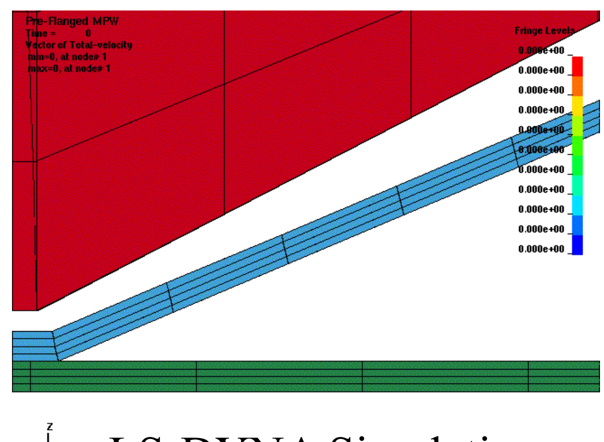
Variation of Initial Launch Angle



Assembled Actuator



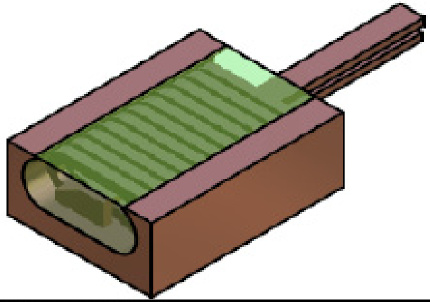
Schematic Illustration

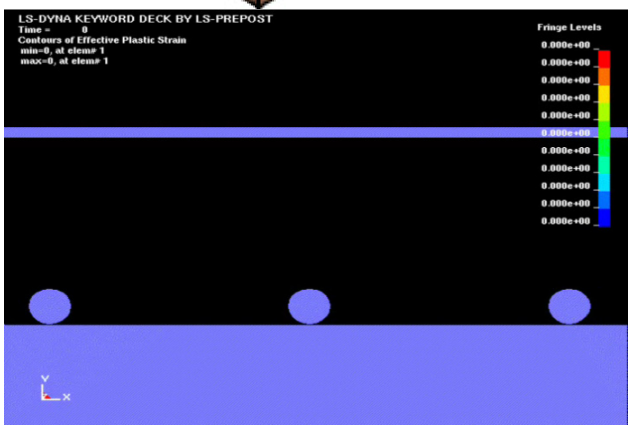


LS-DYNA Simulation

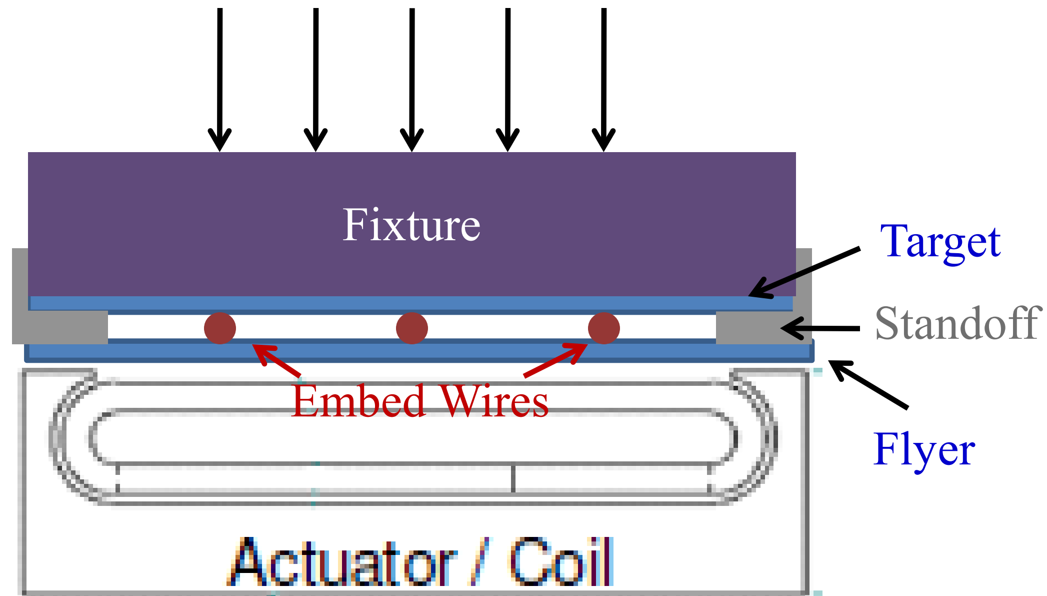
Uniform Pressure Actuator for Plate-to-Plate Welding

Uniform Pressure Actuator





*[*Courtesy to S. Srinivasan]*

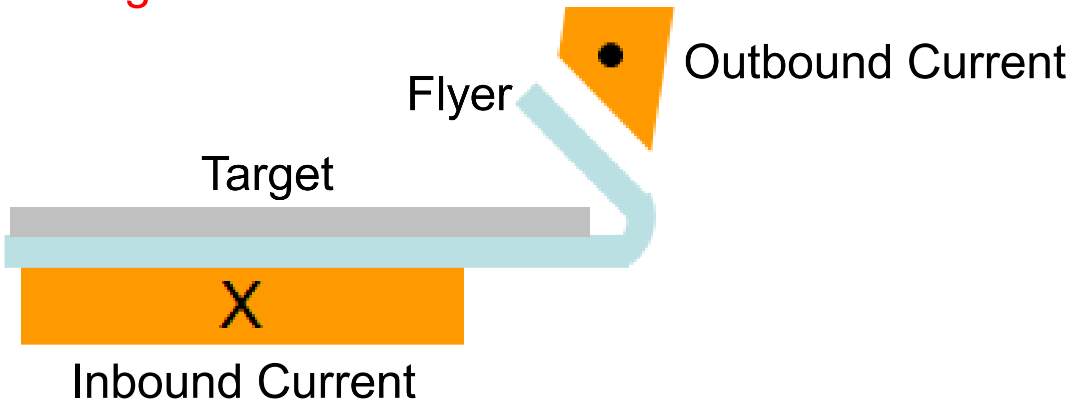


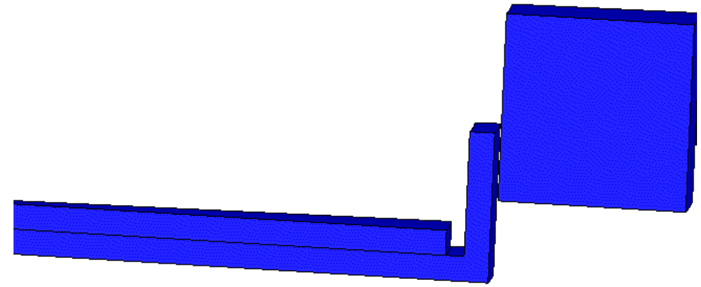
Schematic Illustration

Welded Sample

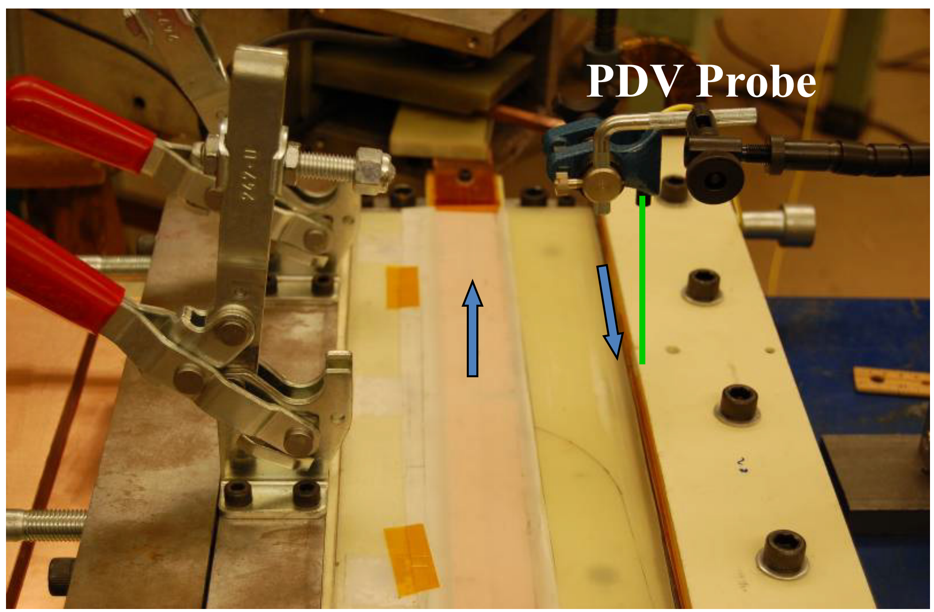
Bar Actuator for Flanging and Welding

Pre-flange Actuator



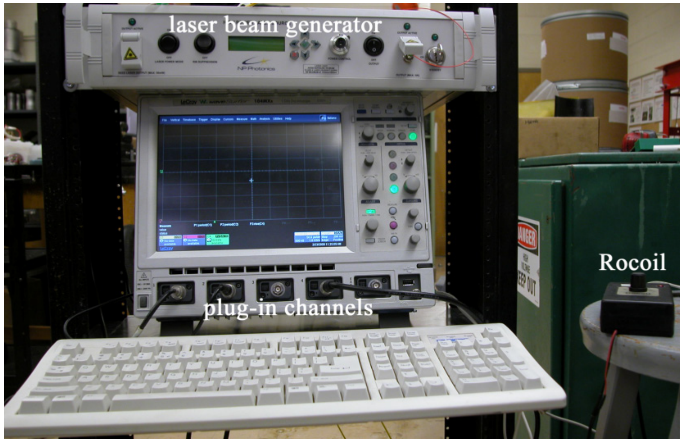


Schematic Illustration

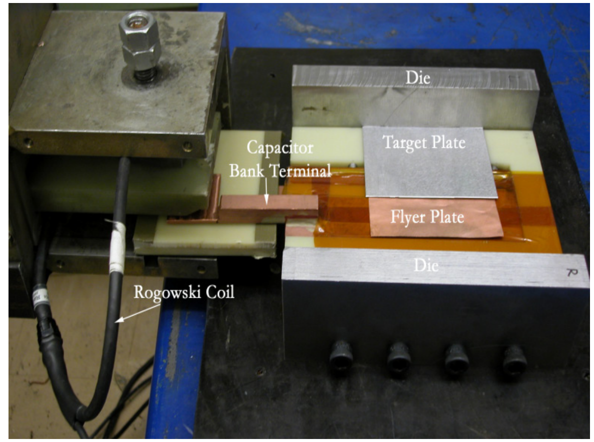


Experimental Setup

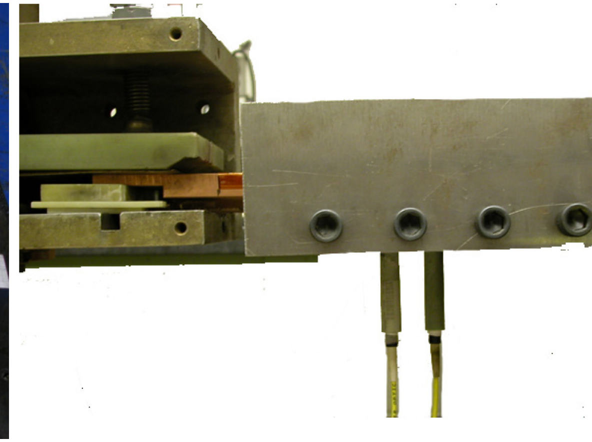
Measurement of Velocity and Current



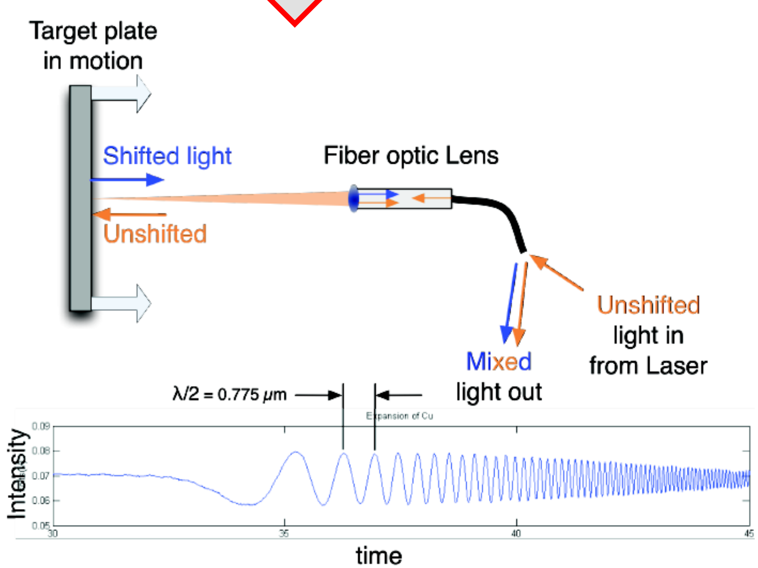
Photon Doppler Velocimetry (PDV)



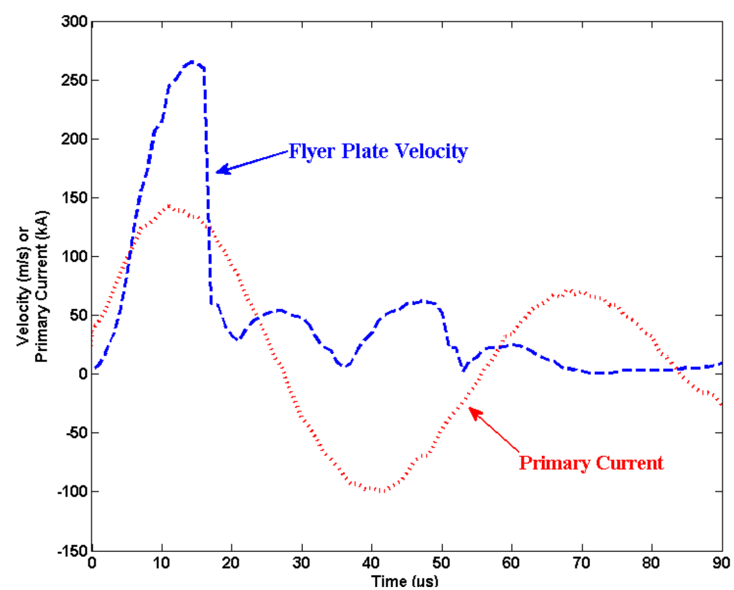
Plug in Rogowski Coil



Probes of Fiber Optic Lens



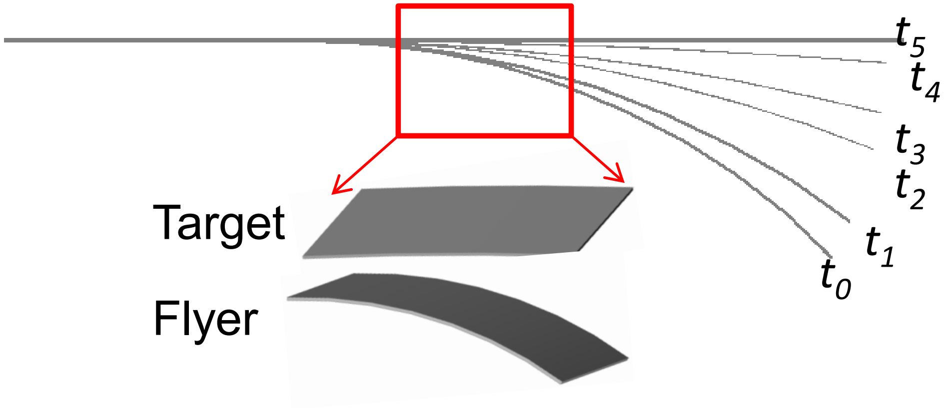
PDV Working Principle



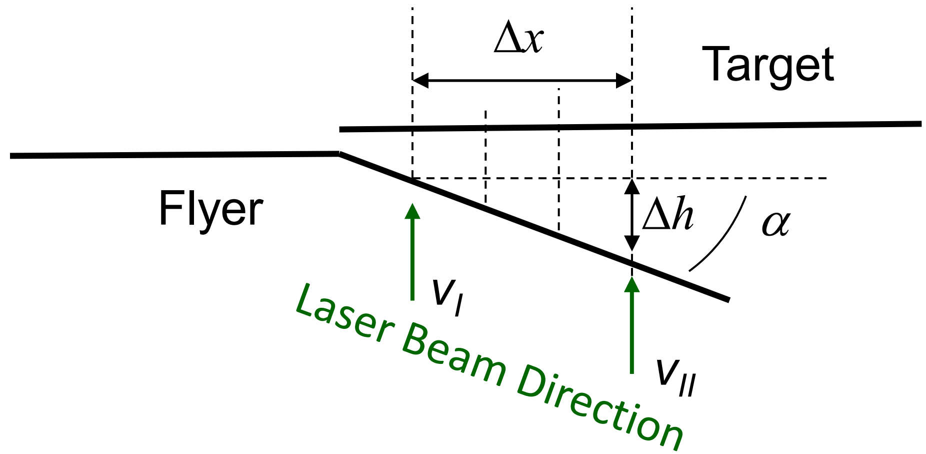
Typical Measured Current and Velocity

Impact Angle Calculation

Movement of Flyer Plate



Mathematic Model



Assume flyer plate is rigid before collision and then calculate impact angle:

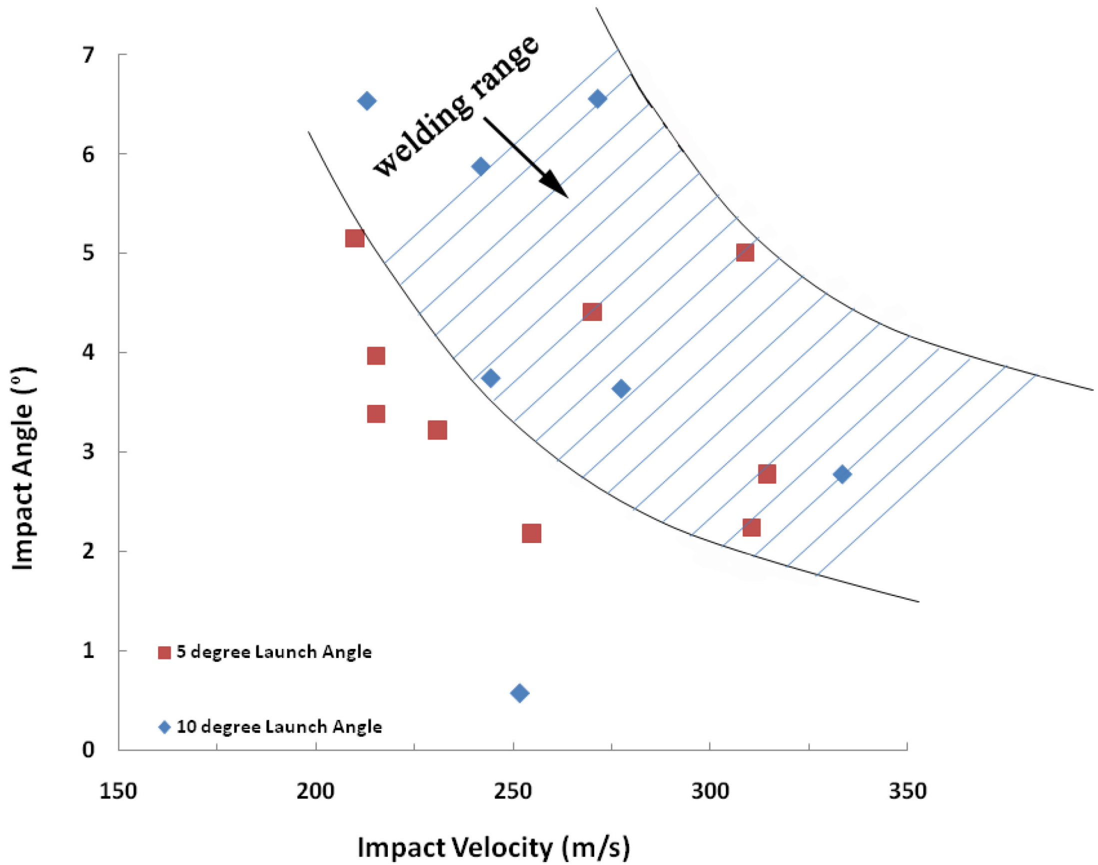
$$\alpha = tg^{-1}\frac{\Delta h}{\Delta x}$$

In which, flyer relative moving distance:

$$\Delta h = \int v_{II}\,dt_{II} - \int v_I\,dt_I$$

Note: v~t data is measured by PDV and Δx is known.

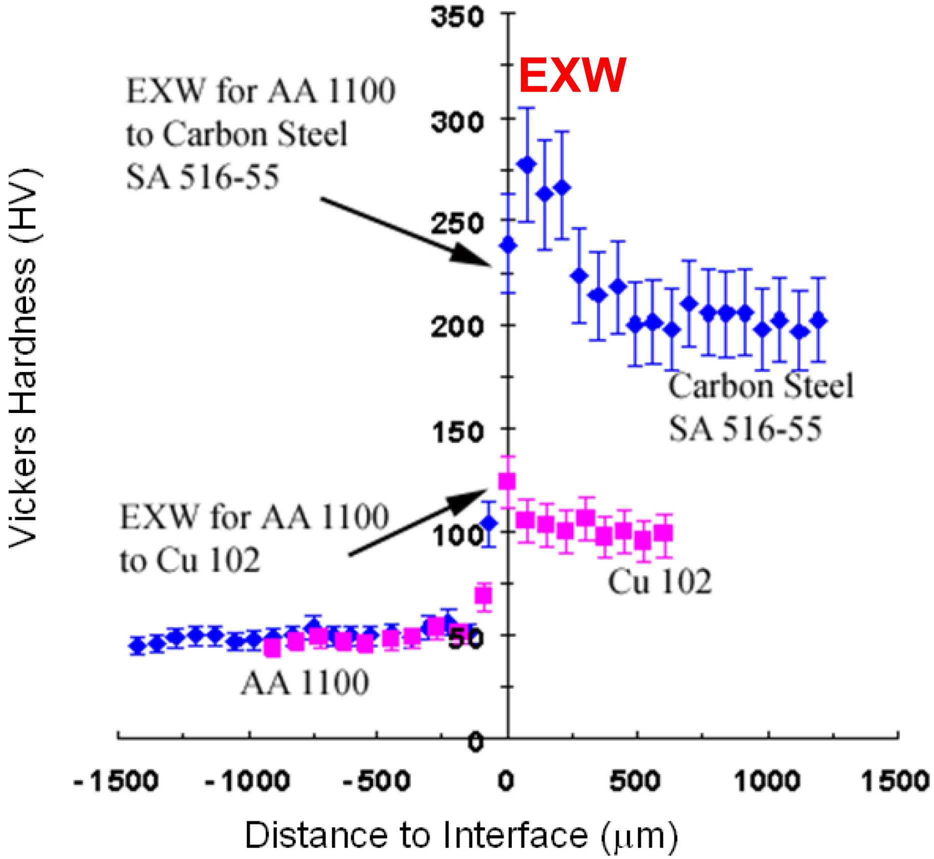
Build up Joining Map

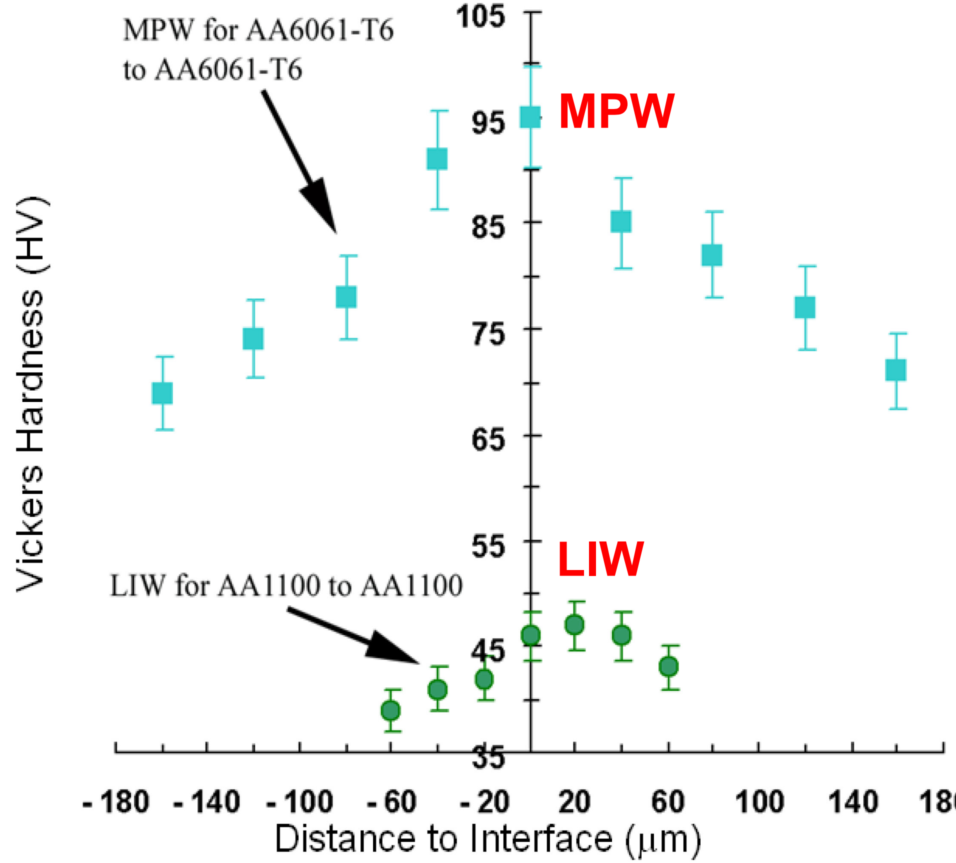


Joining map for Cu110 joints of 0.254mm thick plates

- Effective welding requires proper combination of impact velocity and impact angle.

Mechanical Test: Microhardness

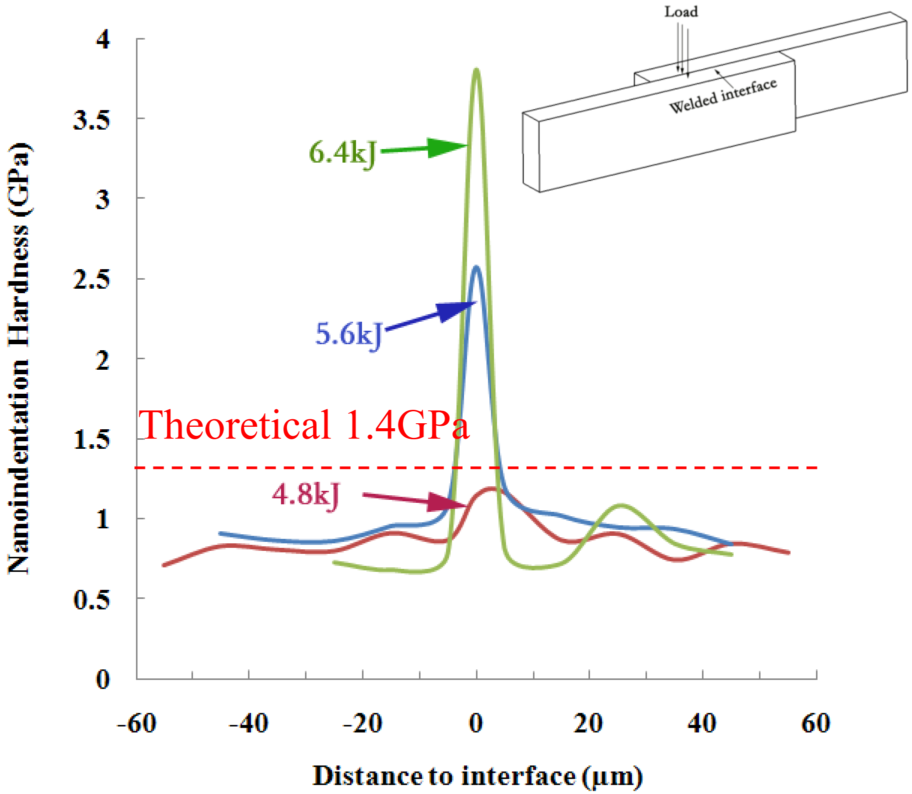




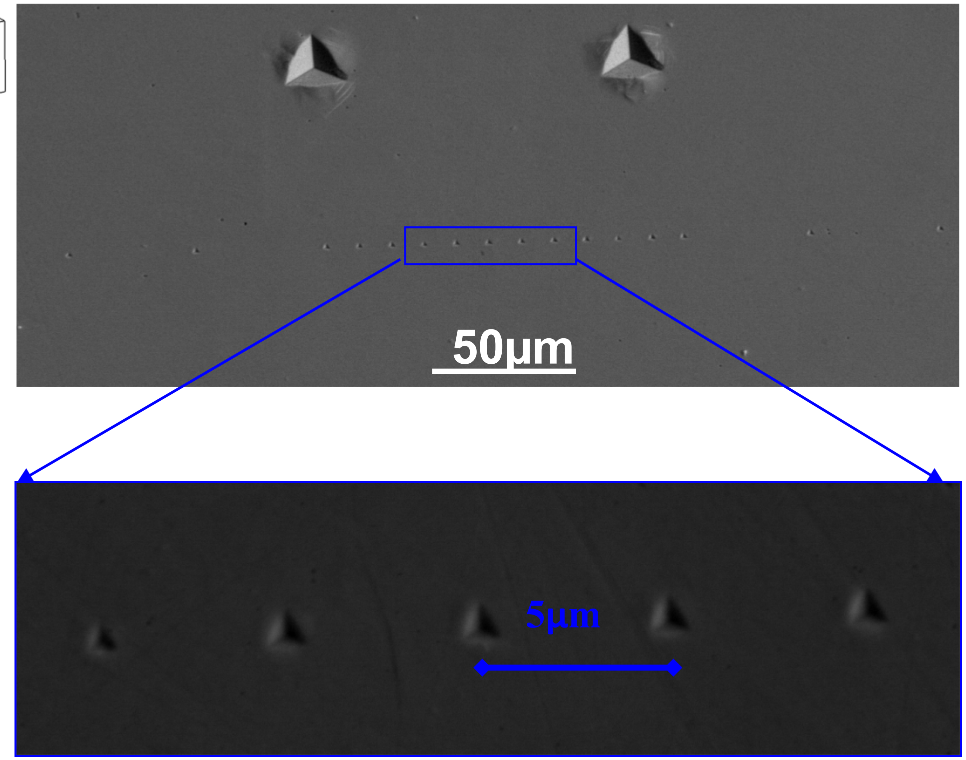
- Improved microhardness along welded interface.
- Width of hardened region scales with impact energy density.

	EXW	MPW	LIW
Hardened Region (μm)	250	50	20
Energy Density (kJ/m^2)	6944	747	53

Mechanical Test: Nanoindentation



data from AA6061 to AA6061 joint

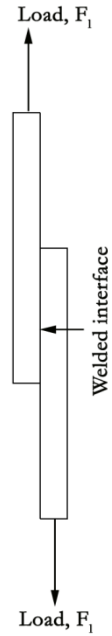


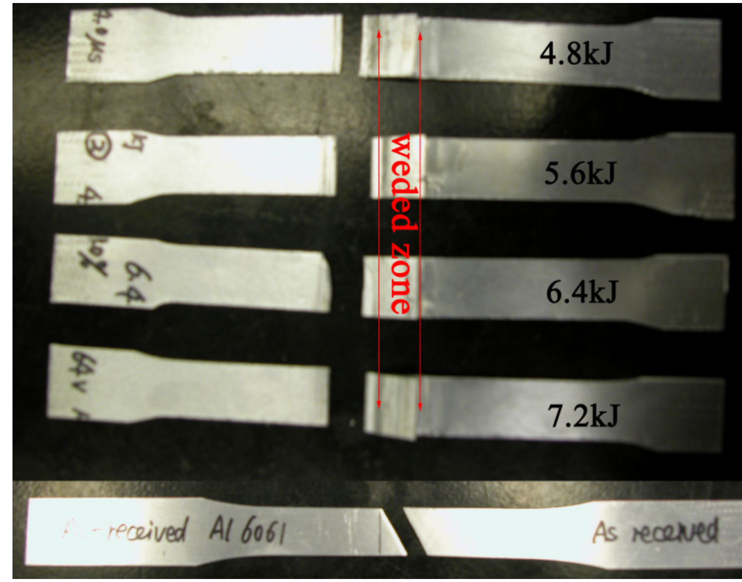
Nanoindentors across interface

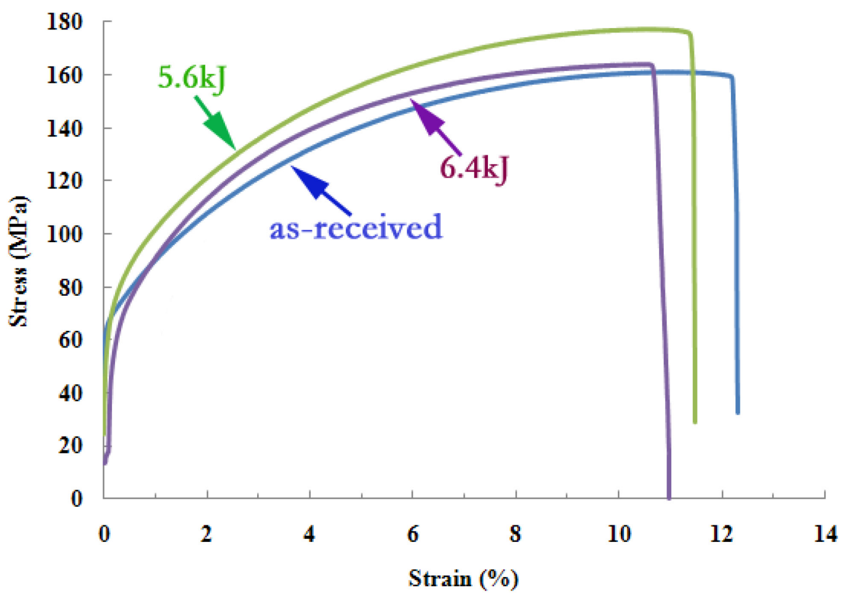
•Indenters transverse interface with 5μm spacing in 50μm wide range on either side of the welded interface.

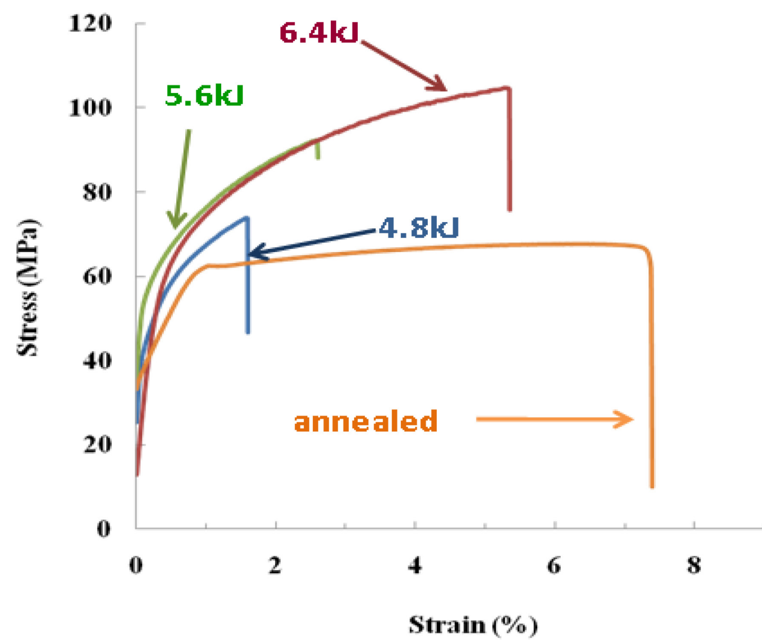
•Hardened region is symmetrical with w.r.t. welded interface. 10μm wide regions on either side have extreme hardness.

Mechanical Test: Lap Shearing

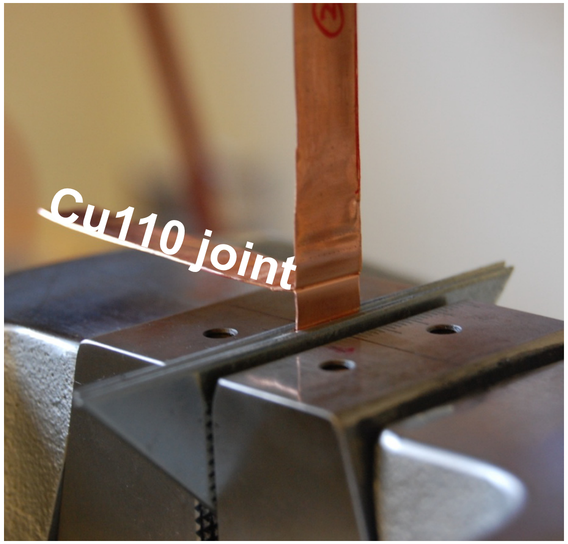


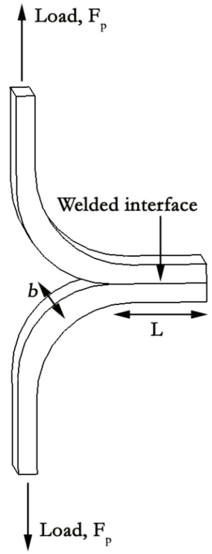




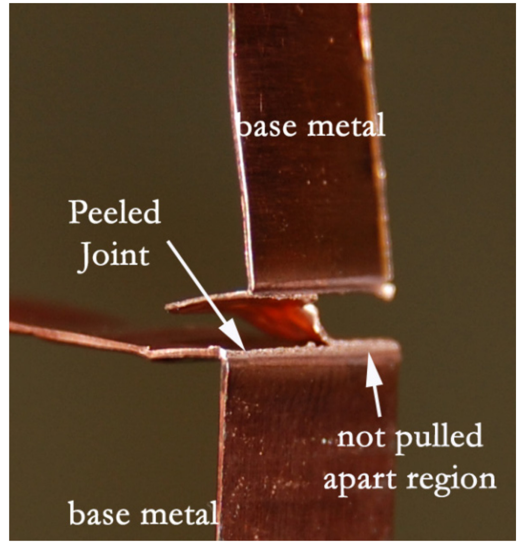


Mechanical Test: Peeling

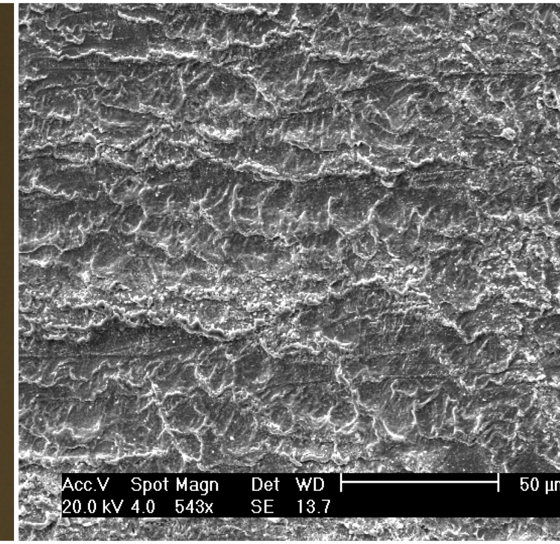




Peeling Test Setup



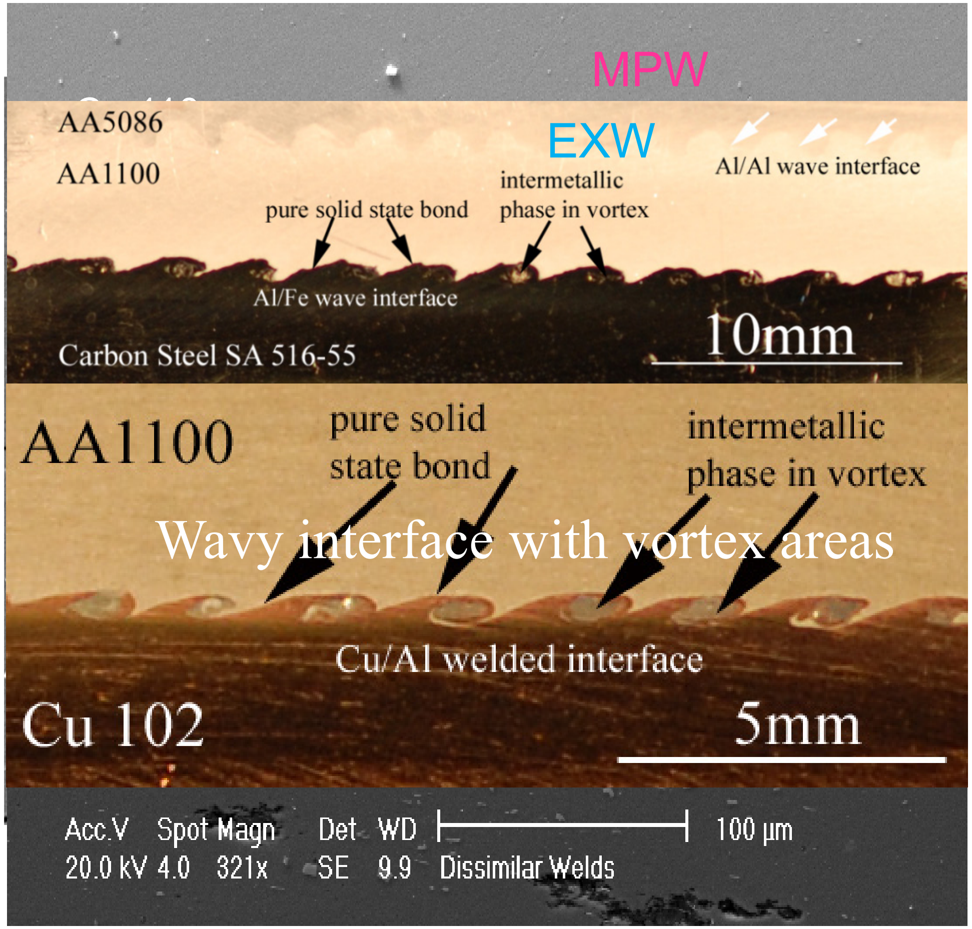
Peeled Sample

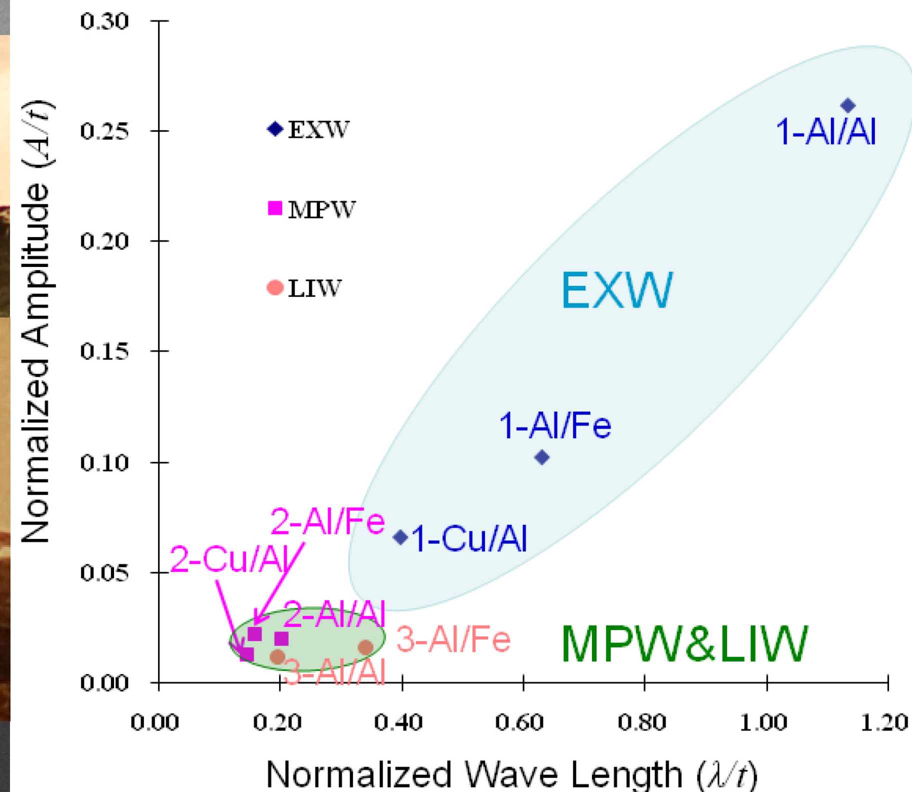


Fracture Surface@5.6kJ

Flyer/Target	Cu110/Cu110		
Impact Energy (kJ)	4.0	4.8	5.6
Joint Peel Strength (N/mm)	0.9	>10.3	>11.4
Failure Mode	through interface	through base metal	through base metal

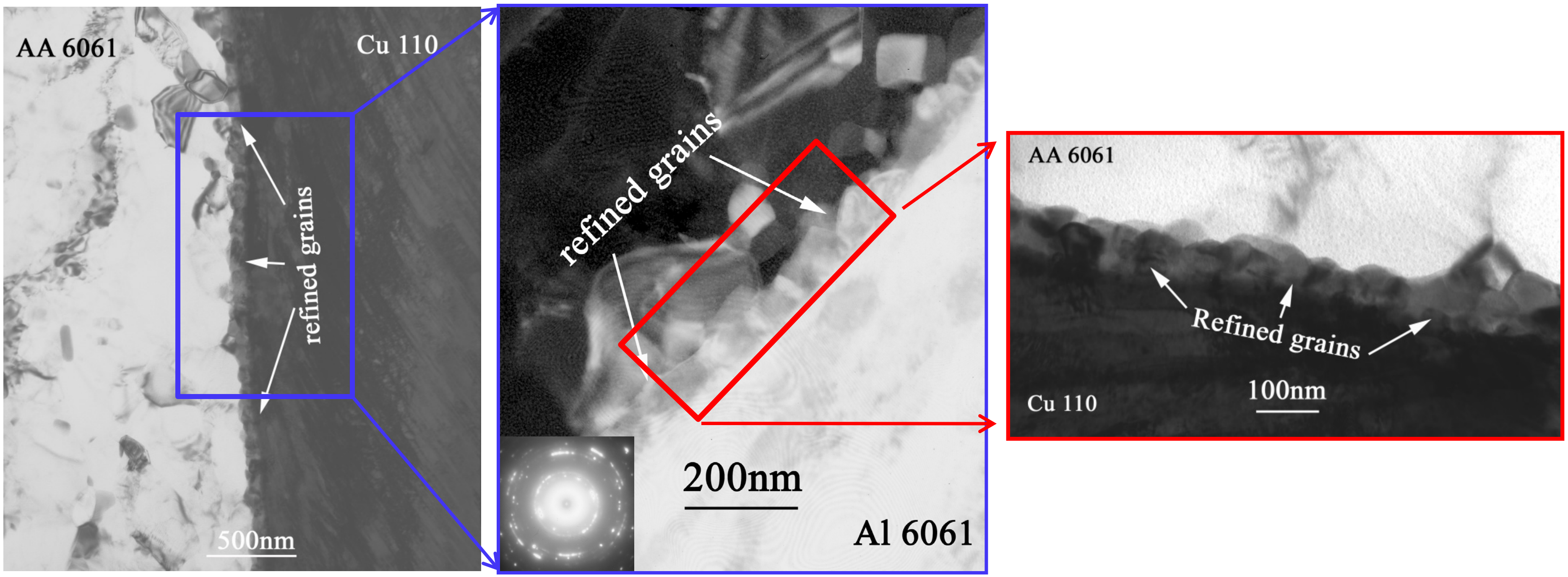
Impact Welded Interface Morphology





- Feasible for all length scales with proper impact angle and impact velocity.
- Can be used for dissimilar materials joining.
- Wavy length and wavy amplitude is proportional to impact energy density.

Interfacial Grain Refinement



- Adiabatic heat and impact pressure make grains along interface undergo severe refinement.
- The average AA6061grain size is ~40µm; the average Cu101 grain size is ~10µm. And the average interfacial grain size falls into nanometer scale.

Conclusions

- Similar to EXW, MPW joining map is also dependent on impact angle and impact velocity.
- Impact welding generates wavy interface. Wave length and amplitude scale with plate thickness and impact energy density.
- Mechanical test indicates impact joint has greater microhardness and shear strength.
- High velocity impact generates ultra fine grain structure along welded interface.

Acknowledgement

- Thanks to electromagnetic forming (EMF) group at OSU, especially Geoff Taber's help on welding experiments.
- Thanks to Pierre L'Eplattenier and Mike Burger's help on LS-DYNA simulation.
- Thanks for graduate student fellowship support from AWS.
- Thanks for SHaRE program at ORNL/DOE.

- Thank you for your attention.