GREAT DESIGNS IN STEEL

TWENTY YEARS

ALTERNATIVE JOINING A/SP RESEARCH RESULTS OF QUASI-STATIC EVALUATION

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PROJECT GOALS

- Identify joining technologies that can provide advantages in UHSS and 3rd Gen AHSS materials compared to resistance spot welding
  - Performance – Peak load and energy absorption
  - Capability – Stack thickness and thickness ratio
  - Robustness – Compatibility with multiple grades and resistance to LME

- Quantify performance (peak load, energy absorption) relative to typical steel grades

PROJECT APPROACH

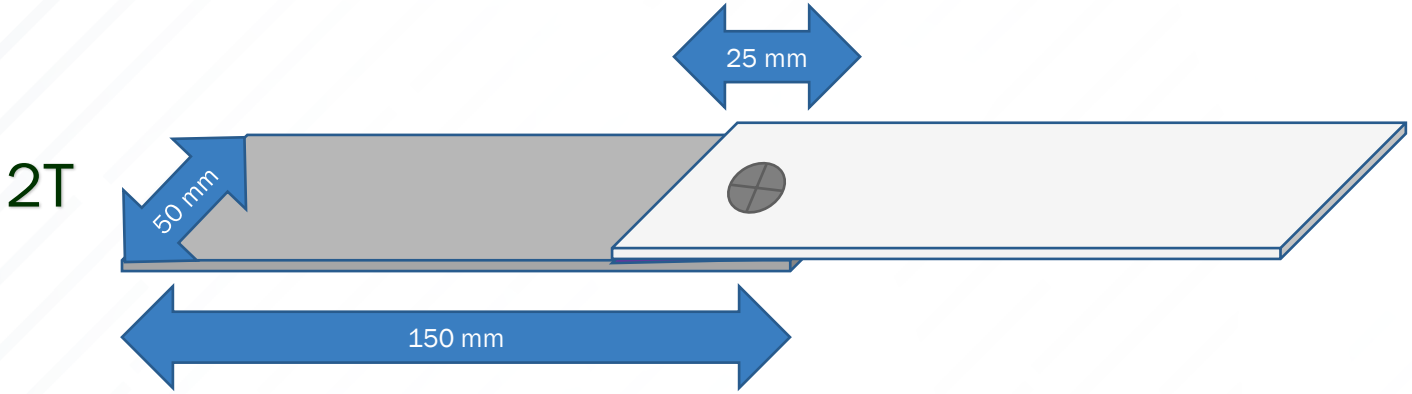
- Sample Configurations and Sizes
  1. Lap Shear 50 mm x 150 mm, standardized with other joining projects
  2. Cross Tension 50 mm x 150 mm
  3. Baseline joints / Advanced material joints
  4. (12) total joints: (3) joints per advanced material / (4) advanced materials
- Joining Technologies
  1. Resistance Spot Weld (RSW)
  2. Mechanical Clinching
  3. Thermally-Assisted Mechanical Clinching
  4. Thermally-Assisted Self Piercing Rivet
- Joint Configurations
  1. Without sealer or adhesive
  2. With structural adhesive

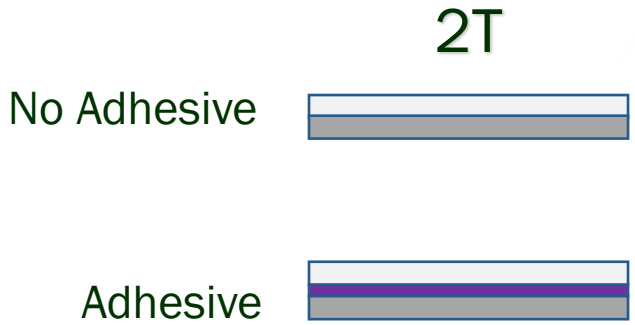
TERMINOLOGY

Naming conventions adopted to avoid trademarks and company-specific naming

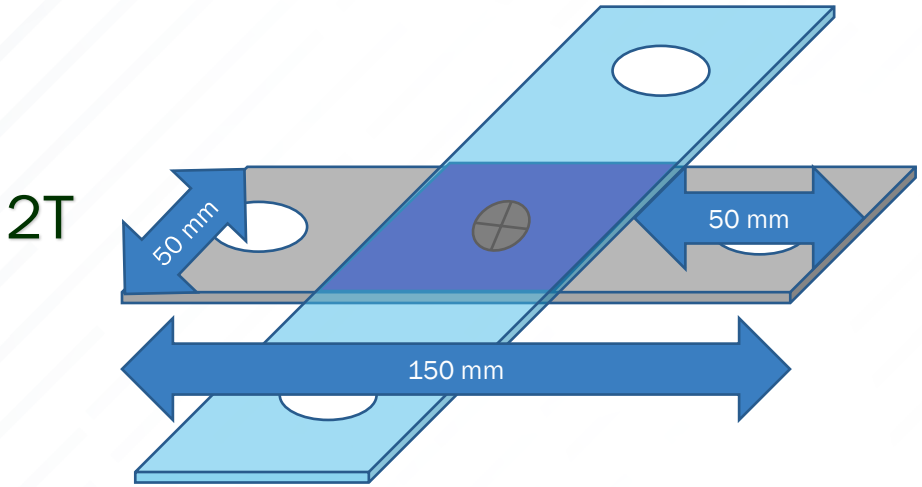
- RSW = Resistance Spot Weld
- TAC = Thermally-Assisted Clinch
- MCL = Mechanical Clinch
- TAR = Thermally-Assisted Rivet

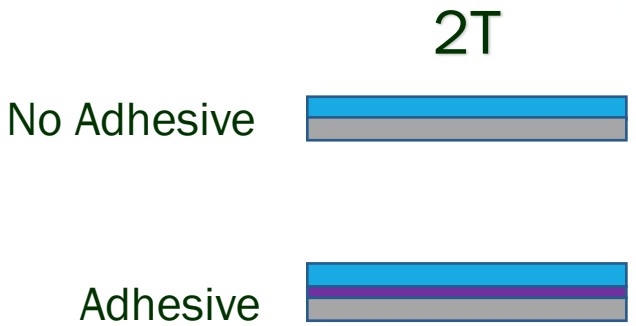
LAP SHEAR



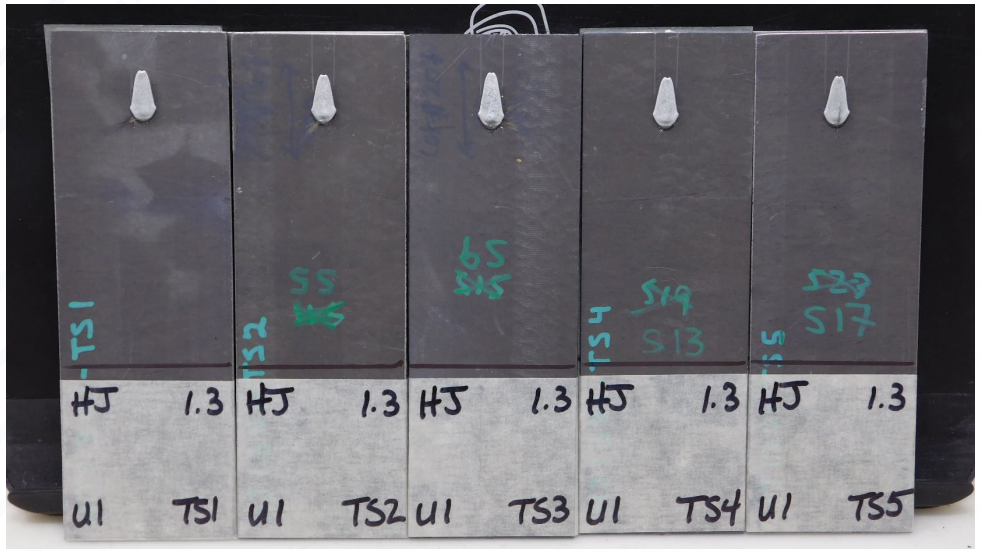


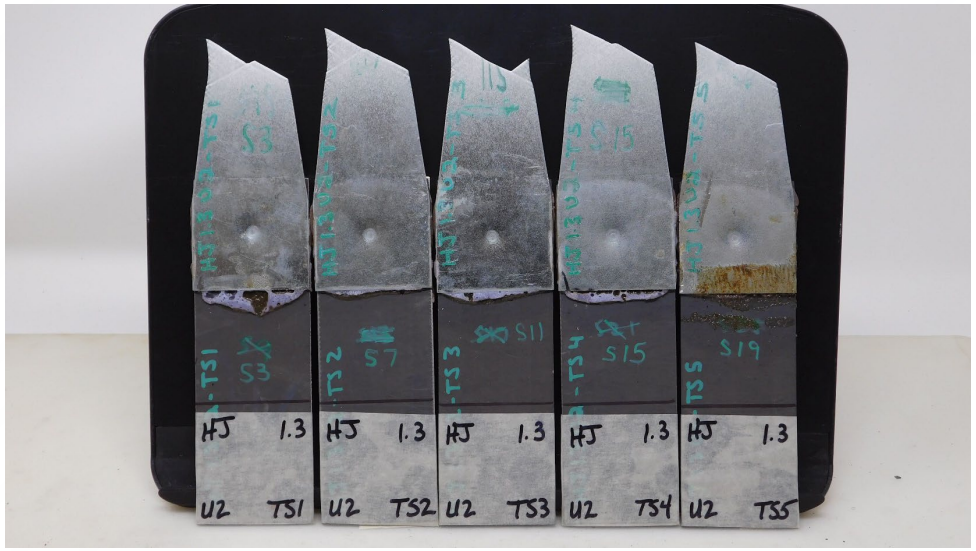
CROSS TENSION





RESISTANCE SPOT WELD





Lap Shear Without Adhesive (Top Left)
Lap Shear With Adhesive (Top Right)
Cross Tension With Adhesive Joint (Bottom Right)

RESULTS MATRIX – RESISTANCE SPOT WELD

Peak Loads		RSW		RSW + Adhesive	
Joint ID	Top / Bottom [Baseline]	Shear	Cross	Shear	Cross
Joint 1	CR04 (0.7) / PHS1300 (1.5) Baseline				
Joint 1	CR04 (0.7) / PHS1800 (1.4) Advanced				
Joint 2	PHS1300 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 3	DP590 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 4	CR04 (0.7) / MS1700 (1.0) [MS1500 (1.2)]				
Joint 5	MS1700 (1.0) [MS1500 (1.2)] / PHS1300 (1.5)				
Joint 6	MS1700 (1.0) [MS1500 (1.2)] / DP780 (1.9)				
Joint 7	RA980 (1.1) [DP780 (1.4)] / DP590 (1.5)				
Joint 8	CR04 (0.7) / RA980 (1.1) [DP780 (1.4)]				
Joint 9	RA980 (1.1) [DP780 (1.4)] / PHS1300 (1.5)				
Joint 10	RA1180 (1.2) [PHS1300 (1.2)] / PHS1300 (1.5)				
Joint 11	CR04 (0.7) / RA1180 (1.2) [PHS1300 (1.2)]				
Joint 12	DP590 (1.0) / RA1180 (1.6) [PHS1300 (1.5)]				

Energy at Break		RSW		RSW + Adhesive	
Joint ID	Top / Bottom [Baseline]	Shear	Cross	Shear	Cross
Joint 1	CR04 (0.7) / PHS1300 (1.5) Baseline				
Joint 1	CR04 (0.7) / PHS1800 (1.4) Advanced				
Joint 2	PHS1300 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 3	DP590 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 4	CR04 (0.7) / MS1700 (1.0) [MS1500 (1.2)]				
Joint 5	MS1700 (1.0) [MS1500 (1.2)] / PHS1300 (1.5)				
Joint 6	MS1700 (1.0) [MS1500 (1.2)] / DP780 (1.9)				
Joint 7	RA980 (1.1) [DP780 (1.4)] / DP590 (1.5)				
Joint 8	CR04 (0.7) / RA980 (1.1) [DP780 (1.4)]				
Joint 9	RA980 (1.1) [DP780 (1.4)] / PHS1300 (1.5)				
Joint 10	RA1180 (1.2) [PHS1300 (1.2)] / PHS1300 (1.5)				
Joint 11	CR04 (0.7) / RA1180 (1.2) [PHS1300 (1.2)]				
Joint 12	DP590 (1.0) / RA1180 (1.6) [PHS1300 (1.5)]				

Versus RSW Baseline | ≥100% | ≥80% | ≥60% | <60% | No Data

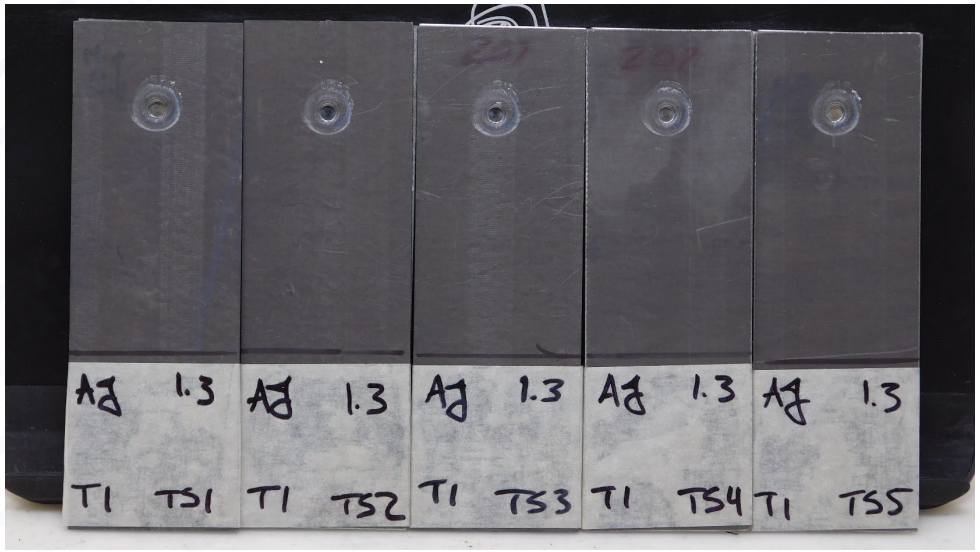
Peak Loads

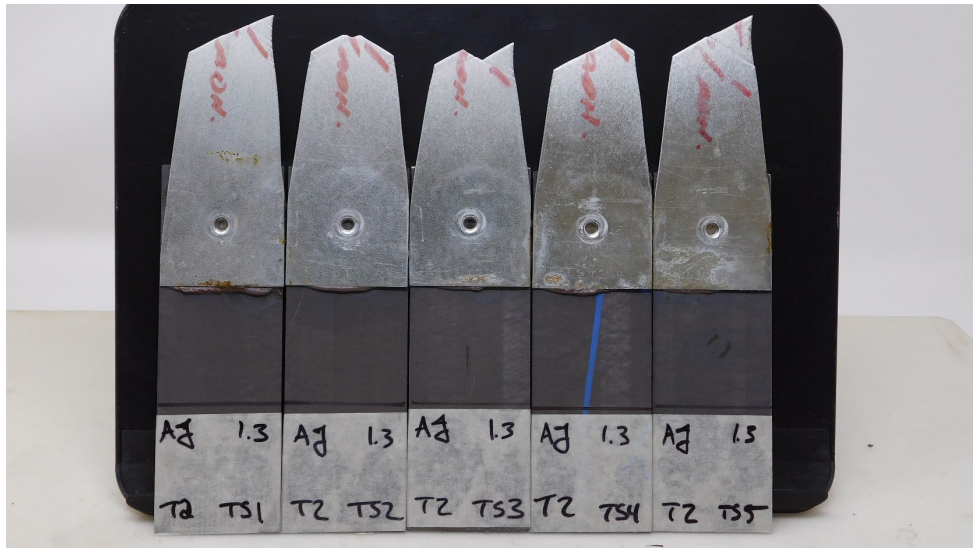
- Most lap shear combinations achieved at least 80% without adhesive, 100% with adhesive
- Most cross tension combinations achieved at least 60% without adhesive, 80% with adhesive

Energy at Break

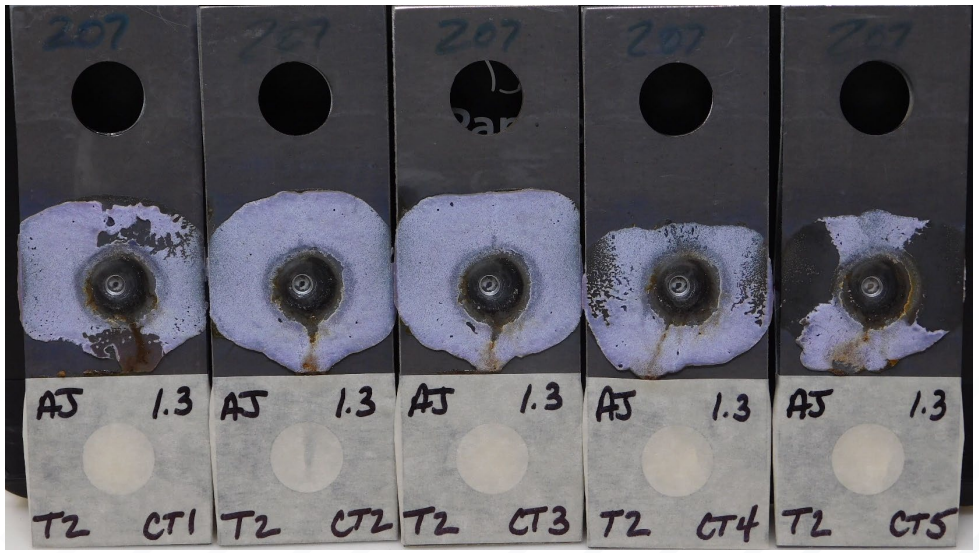
- Most lap shear combinations achieved at least 80% without adhesive, 100% with adhesive
- Over half of cross tension combinations achieved at least 60% without adhesive, most achieved 60% with adhesive

THERMALLY ASSISTED CLINCH





Lap Shear Without Adhesive (Top Left)
Lap Shear With Adhesive (Top Right)
Cross Tension With Adhesive Joint (Bottom Right)



RESULTS MATRIX – THERMALLY ASSISTED CLINCH

Peak Loads		TAC		TAC + Adhesive	
Joint ID	Top / Bottom [Baseline]	Shear	Cross	Shear	Cross
Joint 1	CR04 (0.7) / PHS1300 (1.5) Baseline				
Joint 1	CR04 (0.7) / PHS1800 (1.4) Advanced				
Joint 2	PHS1300 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 3	DP590 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 4	CR04 (0.7) / MS1700 (1.0) [MS1500 (1.2)]				
Joint 5	MS1700 (1.0) [MS1500 (1.2)] / PHS1300 (1.5)				
Joint 6	MS1700 (1.0) [MS1500 (1.2)] / DP780 (1.9)				
Joint 7	RA980 (1.1) [DP780 (1.4)] / DP590 (1.5)				
Joint 8	CR04 (0.7) / RA980 (1.1) [DP780 (1.4)]				
Joint 9	RA980 (1.1) [DP780 (1.4)] / PHS1300 (1.5)				
Joint 10	RA1180 (1.2) [PHS1300 (1.2)] / PHS1300 (1.5)				
Joint 11	CR04 (0.7) / RA1180 (1.2) [PHS1300 (1.2)]				
Joint 12	DP590 (1.0) / RA1180 (1.6) [PHS1300 (1.5)]				

Energy at Break		A-TAC		TAC + Adhesive	
Joint ID	Top / Bottom [Baseline]	Shear	Cross	Shear	Cross
Joint 1	CR04 (0.7) / PHS1300 (1.5) Baseline				
Joint 1	CR04 (0.7) / PHS1800 (1.4) Advanced				
Joint 2	PHS1300 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 3	DP590 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 4	CR04 (0.7) / MS1700 (1.0) [MS1500 (1.2)]				
Joint 5	MS1700 (1.0) [MS1500 (1.2)] / PHS1300 (1.5)				
Joint 6	MS1700 (1.0) [MS1500 (1.2)] / DP780 (1.9)				
Joint 7	RA980 (1.1) [DP780 (1.4)] / DP590 (1.5)				
Joint 8	CR04 (0.7) / RA980 (1.1) [DP780 (1.4)]				
Joint 9	RA980 (1.1) [DP780 (1.4)] / PHS1300 (1.5)				
Joint 10	RA1180 (1.2) [PHS1300 (1.2)] / PHS1300 (1.5)				
Joint 11	CR04 (0.7) / RA1180 (1.2) [PHS1300 (1.2)]				
Joint 12	DP590 (1.0) / RA1180 (1.6) [PHS1300 (1.5)]				

Versus RSW Baseline: ≥100% | ≥80% | ≥60% | <60% | No Data

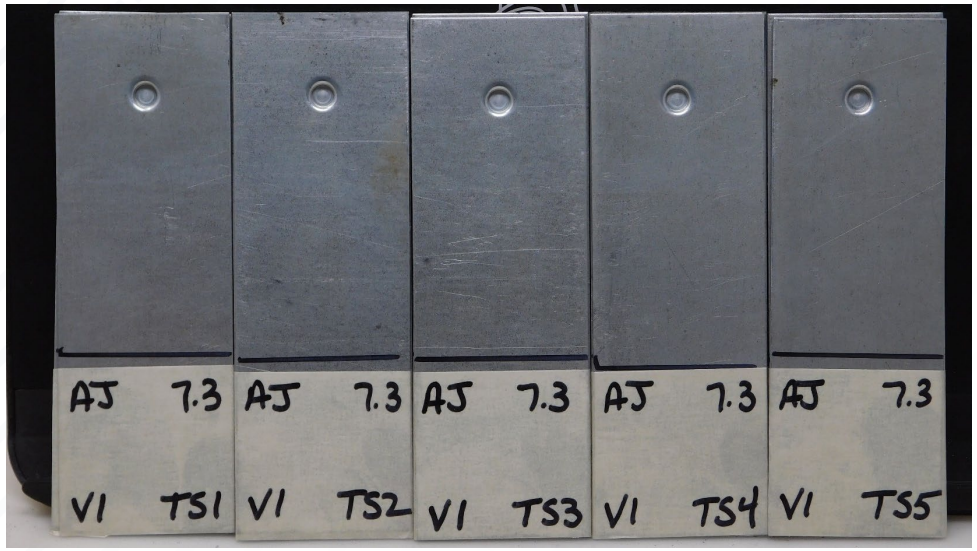
Peak Loads

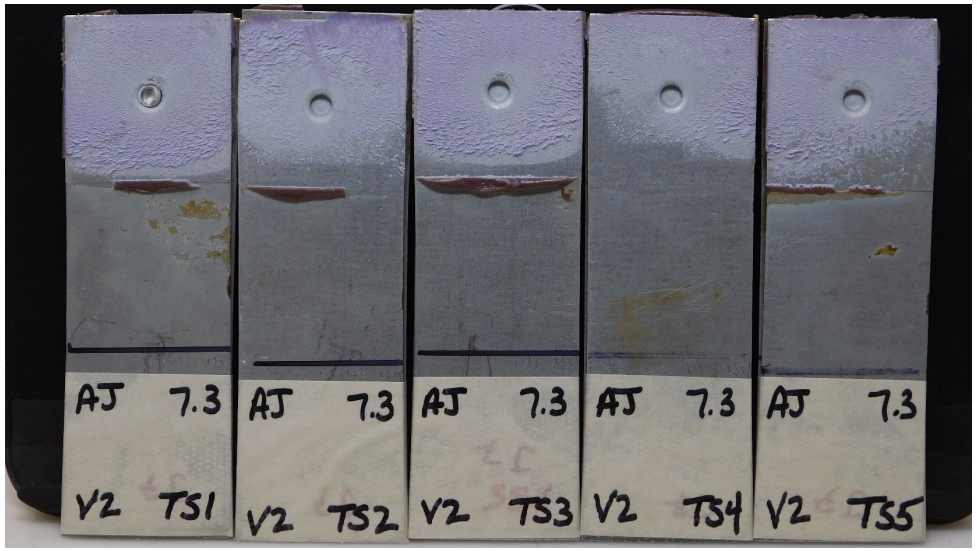
- Several combinations were not feasible
- Most lap shear combinations achieved <60% without adhesive, >80% with adhesive
- Fewer than half of cross tension combinations achieved 60% without adhesive, over half achieved 60% with adhesive

Energy at Break

- Most lap shear combinations achieved <60% without adhesive, more than half achieved 80% with adhesive
- Most cross tension combinations achieved <60% without adhesive, over half achieved 60% with adhesive

MECHANICAL CLINCH





Lap Shear Without Adhesive (Top Left)
Lap Shear With Adhesive (Top Right)
Cross Tension With Adhesive Joint (Bottom Right)

RESULTS MATRIX — MECHANICAL CLINCH

Peak Loads		MCL		MCL + Adhesive	
Joint ID	Top / Bottom [Baseline]	Shear	Cross	Shear	Cross
Joint 1	CR04 (0.7) / PHS1300 (1.5) Baseline				
Joint 1	CR04 (0.7) / PHS1800 (1.4) Advanced				
Joint 2	PHS1300 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 3	DP590 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 4	CR04 (0.7) / MS1700 (1.0) [MS1500 (1.2)]				
Joint 5	MS1700 (1.0) [MS1500 (1.2)] / PHS1300 (1.5)				
Joint 6	MS1700 (1.0) [MS1500 (1.2)] / DP780 (1.9)				
Joint 7	RA980 (1.1) [DP780 (1.4)] / DP590 (1.5)				
Joint 8	CR04 (0.7) / RA980 (1.1) [DP780 (1.4)]				
Joint 9	RA980 (1.1) [DP780 (1.4)] / PHS1300 (1.5)				
Joint 10	RA1180 (1.2) [PHS1300 (1.2)] / PHS1300 (1.5)				
Joint 11	CR04 (0.7) / RA1180 (1.2) [PHS1300 (1.2)]				
Joint 12	DP590 (1.0) / RA1180 (1.6) [PHS1300 (1.5)]				

Energy at Break		MCL		MCL + Adhesive	
Joint ID	Top / Bottom [Baseline]	Shear	Cross	Shear	Cross
Joint 1	CR04 (0.7) / PHS1300 (1.5) Baseline				
Joint 1	CR04 (0.7) / PHS1800 (1.4) Advanced				
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Joint 9	RA980 (1.1) [DP780 (1.4)] / PHS1300 (1.5)				
Joint 10	RA1180 (1.2) [PHS1300 (1.2)] / PHS1300 (1.5)				
Joint 11	CR04 (0.7) / RA1180 (1.2) [PHS1300 (1.2)]				
Joint 12	DP590 (1.0) / RA1180 (1.6) [PHS1300 (1.5)]				

Versus RSW Baseline: ≥100% | ≥80% | ≥60% | <60% | No Data

Peak Loads

- Most combinations were not feasible, as expected
- Most stacks achieved <60% without adhesive
- Stacks joining mild steel to RA steel achieved 100% in shear and cross tension with adhesive

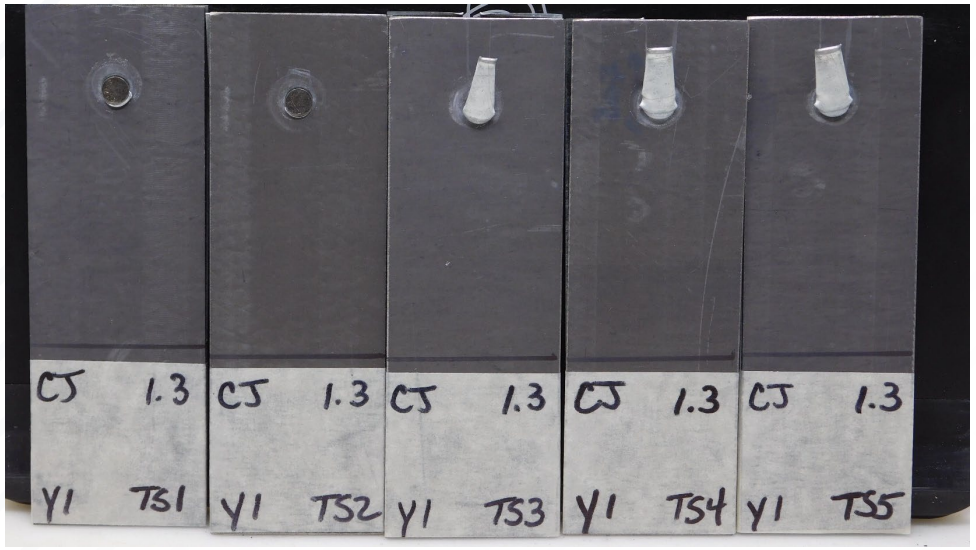
Energy at Break

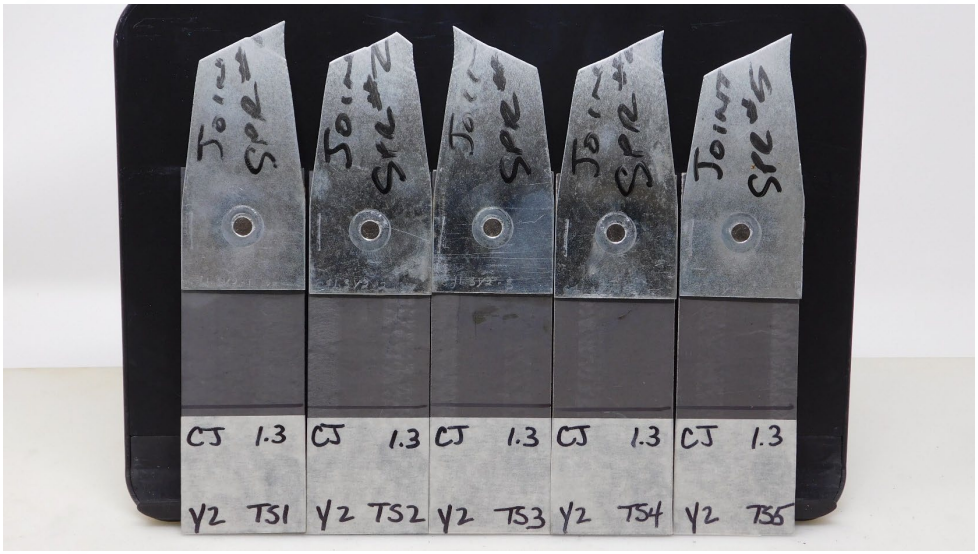
- All stacks achieved <60% without adhesive
- Stacks joining mild steel to RA steel achieved 100% in shear and cross tension with adhesive

Observations

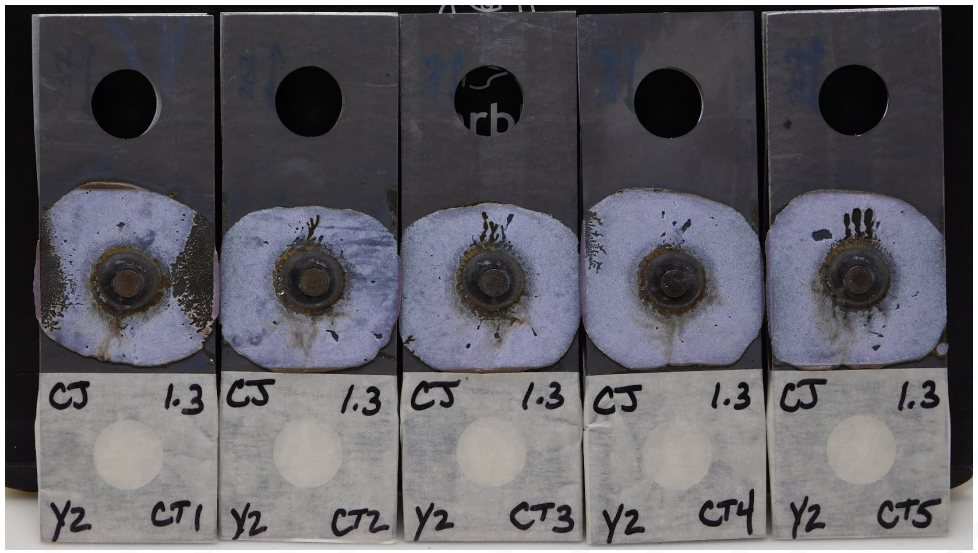
- Room temperature process is favorable for adhesives

THERMALLY ASSISTED RIVET





Lap Shear Without Adhesive (Top Left)
Lap Shear With Adhesive (Top Right)
Cross Tension With Adhesive Joint (Bottom Right)



RESULTS MATRIX — THERMALLY ASSISTED RIVET

Peak Loads

Joint ID	Top / Bottom [Baseline]	TAR		TAR + Adhesive	
		Shear	Cross	Shear	Cross
Joint 1	CR04 (0.7) / PHS1300 (1.5) Baseline				
Joint 1	CR04 (0.7) / PHS1800 (1.4) Advanced				
Joint 2	PHS1300 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 3	DP590 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 4	CR04 (0.7) / MS1700 (1.0) [MS1500 (1.2)]				
Joint 5	MS1700 (1.0) [MS1500 (1.2)] / PHS1300 (1.5)				
Joint 6	MS1700 (1.0) [MS1500 (1.2)] / DP780 (1.9)				
Joint 7	RA980 (1.1) [DP780 (1.4)] / DP590 (1.5)				
Joint 8	CR04 (0.7) / RA980 (1.1) [DP780 (1.4)]				
Joint 9	RA980 (1.1) [DP780 (1.4)] / PHS1300 (1.5)				
Joint 10	RA1180 (1.2) [PHS1300 (1.2)] / PHS1300 (1.5)				
Joint 11	CR04 (0.7) / RA1180 (1.2) [PHS1300 (1.2)]				
Joint 12	DP590 (1.0) / RA1180 (1.6) [PHS1300 (1.5)]				

Energy at Break

Joint ID	Top / Bottom [Baseline]	TAR		TAR + Adhesive	
		Shear	Cross	Shear	Cross
Joint 1	CR04 (0.7) / PHS1300 (1.5) Baseline				
Joint 1	CR04 (0.7) / PHS1800 (1.4) Advanced				
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Joint 3	DP590 (1.2) / PHS1800 (1.4) [PHS1300 (1.5)]				
Joint 4	CR04 (0.7) / MS1700 (1.0) [MS1500 (1.2)]				
Joint 5	MS1700 (1.0) [MS1500 (1.2)] / PHS1300 (1.5)				
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Joint 11	CR04 (0.7) / RA1180 (1.2) [PHS1300 (1.2)]				
Joint 12	DP590 (1.0) / RA1180 (1.6) [PHS1300 (1.5)]				

Versus RSW Baseline: ≥100% | ≥80% | ≥60% | <60% | No Data

Peak Loads

- Half of lap shear combinations achieved 80% without adhesive, most combinations achieved 80% with adhesive
- More than half of cross tension combinations achieved 80% without adhesive, results are similar with adhesive

Energy at Break

- Half of lap shear combinations achieved 80% without adhesive, most combinations achieved 80% with adhesive
- More than half of cross tension combinations achieved 100% without adhesive, most combinations achieved 80% with adhesive

Observations

- Only alternative joining technology to feasibly make 100% of joint combinations

PROJECT CONCLUSIONS AND RECOMMENDATIONS

All (3) alternative joining technologies performed well enough to progress to phase 2 for cyclic fatigue testing

- Thermally Assisted Clinch was generally weak in quasi-static, but performed well enough with adhesive to investigate for fatigue properties
- Mechanical Clinch was interesting for Retained Austenite steels where it was both feasible and not subject to Liquid Metal Embrittlement
- Thermally Assisted SPR was able to make all of the target joints and exhibited cross tension strength that was superior to baseline in some cases

Recommendations

- Evaluation of alternative structural adhesives that are not optimized for welding though
- Evaluation of high thickness ratio combinations outside of typical RSW range

THANK YOU / FOR MORE INFORMATION

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More Questions? Meet Bryan at the Auto/Steel Partnership booth after this presentation.

Auto/Steel Partnership

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