GREAT DESIGNS IN STEEL

TWENTY YEARS

# LASER WELDING OF 2000 MPa PRESS HARDENED STEEL

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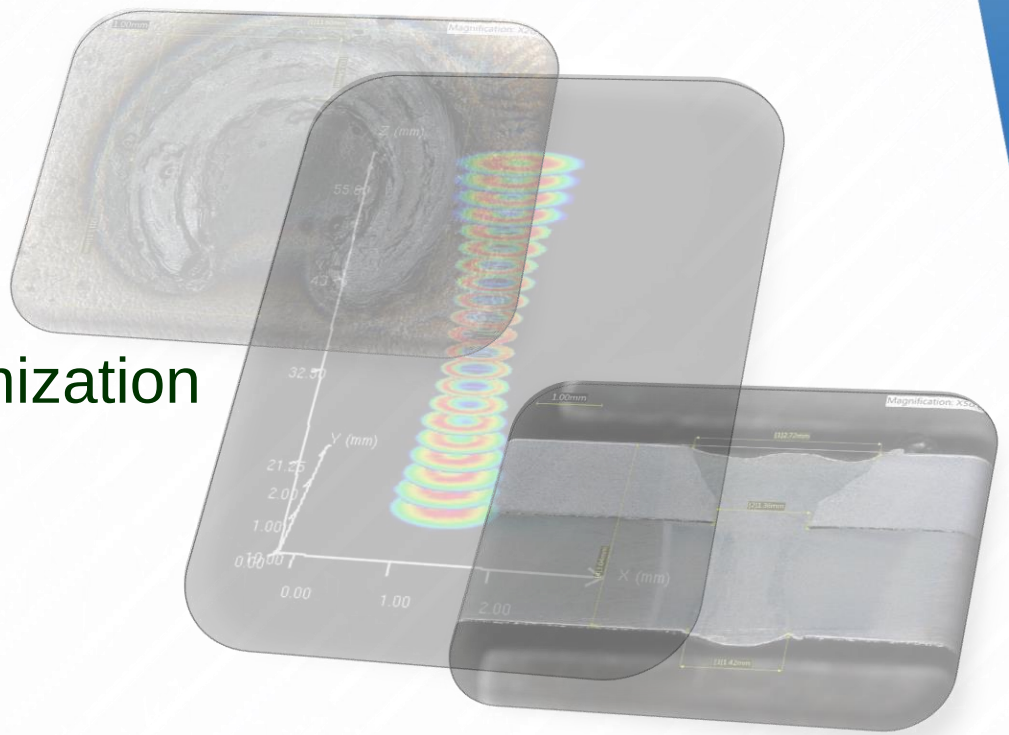
Ford Motor Company and Coherent

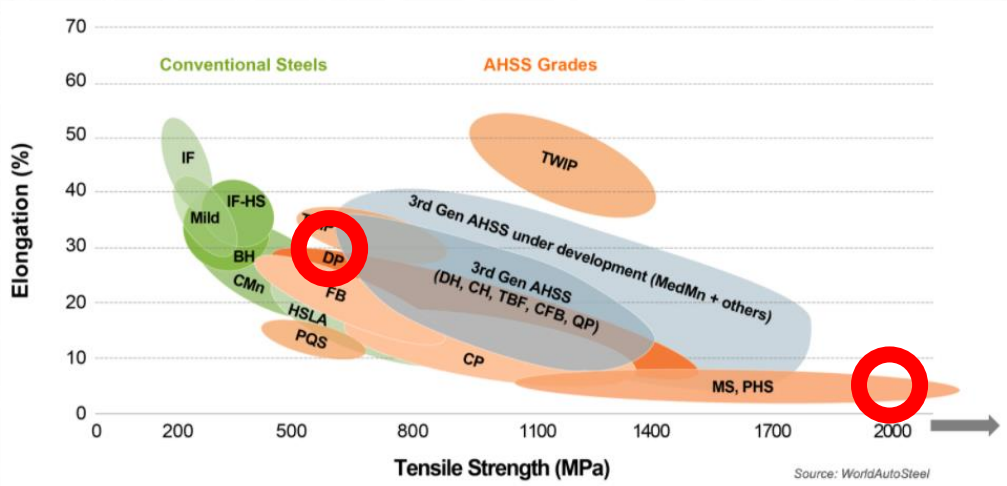
# AGENDA

- Joint Definition
- First Trials
- Laser Welding Development & Optimization
  - Linear Weld
  - Circular Weld
- Weld Strength Overview
- Prototype Insights
- Conclusions

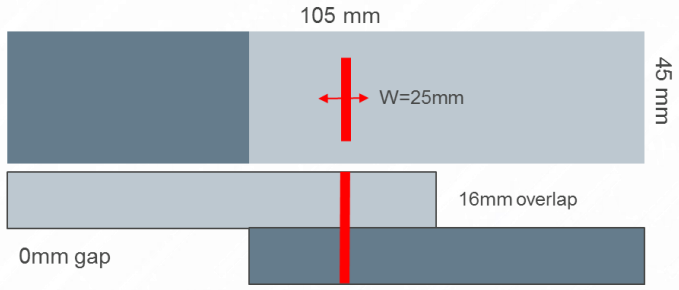


# JOINT DEFINITION

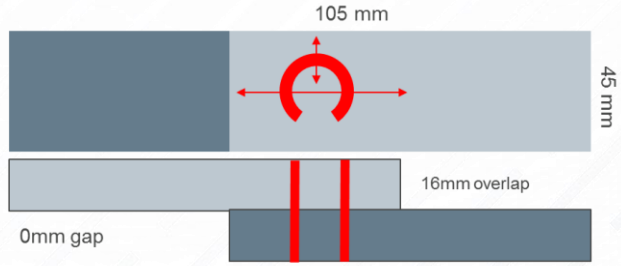
Material
- 1.2 mm DP600 UN (Top)
- 1.8 mm 2000 MPa PHS AS150 (Bottom)




Joint Configuration
- Lap shear
  - Coupon size: 45x105mm
  - Overlap: 16mm
- 25mm Linear welds
- Ø10mm Circular welds




Linear weld

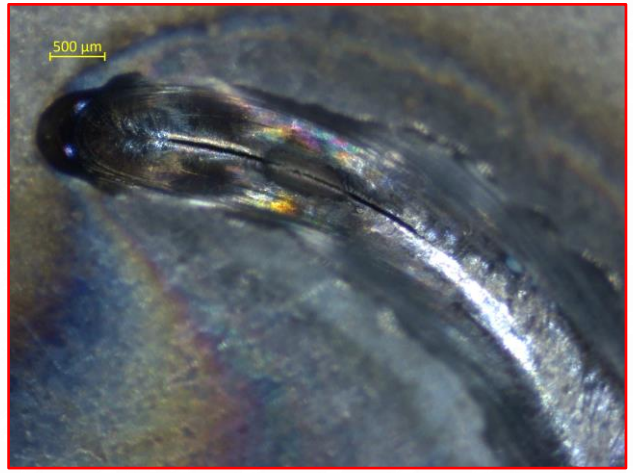



Circular weld

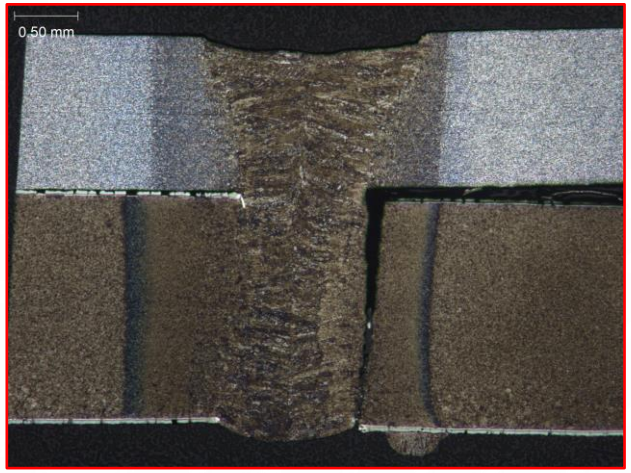
# FIRST TRIALS

Preliminary welding trials performed with standard laser equipment revealed cracks in circular laser welds.

- Common crack
- Premature termination
- Low alloy element segregation




Centerline crack




Through crack

- High residual stresses
- Sensitive microstructure
- Excess hydrogen

Benefits of circular welds:

- Weld geometry can fit in constraint/narrow areas
- Circular welds can take higher external loads than linear welds

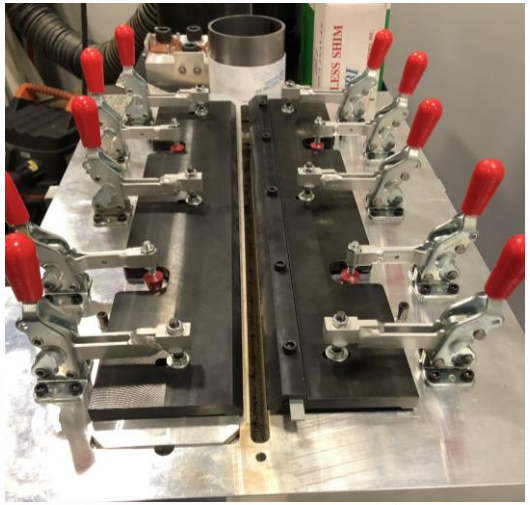
**These conditions and weld geometry benefits encouraged the team to seek weld optimization with advanced laser equipment.**

# LASER WELDING SETUP

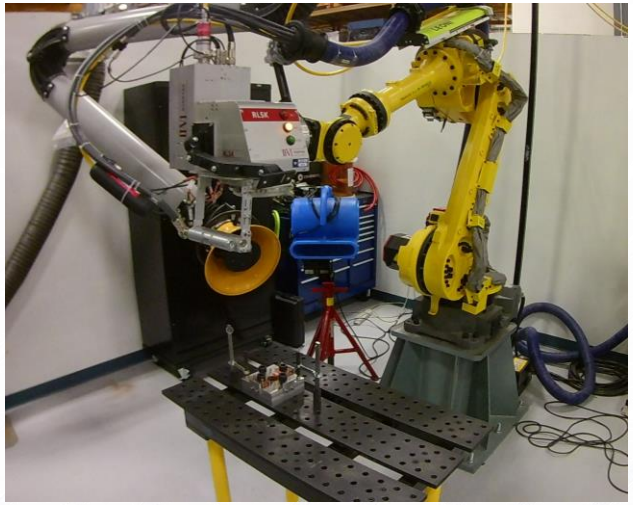
Laser
- Coherent ARM Fiber Laser
  - Coaxial Fiber - Core 100µm / Ring 290µm

Optic
- II-VI HIGHYAG RLSK scanner – 3X magnification

Plume Suppression
- Squirrel cage blower

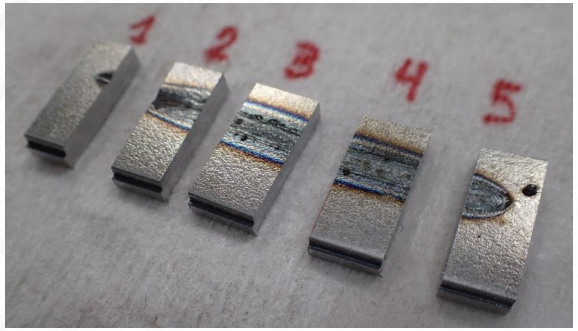
Weld Fixture



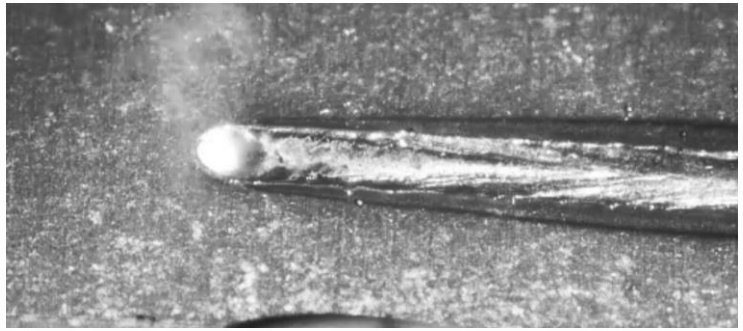
Weld Lab Setup

# LINEAR WELD OVERVIEW

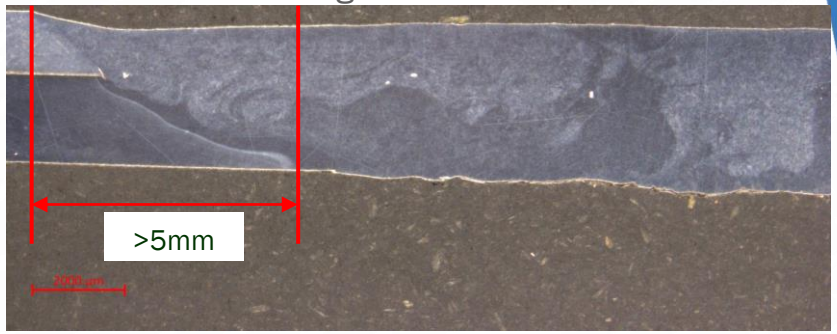
Top View



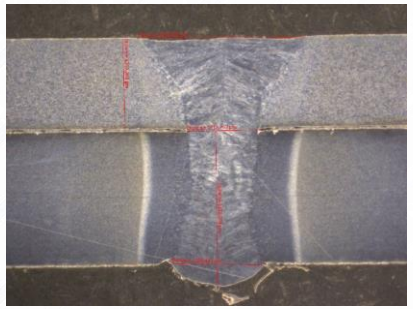

Slow motion linear weld



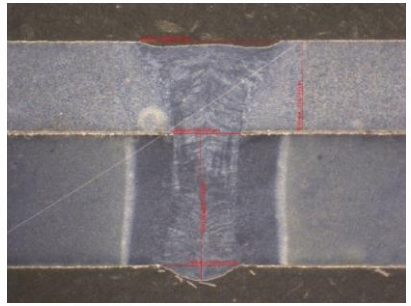
Longitudinal X-section



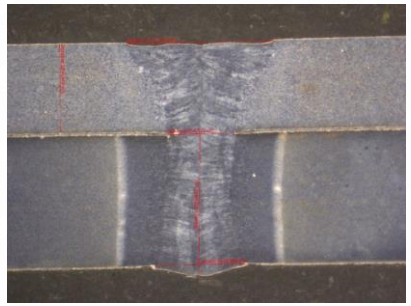

Cross section Analysis



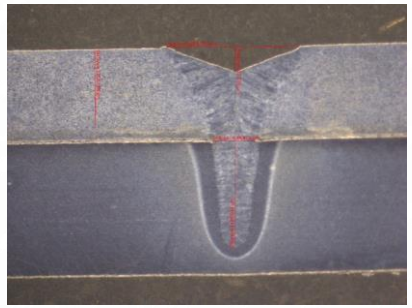
Start



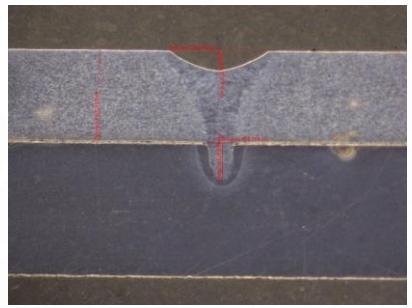
Near middle



Middle



Near end



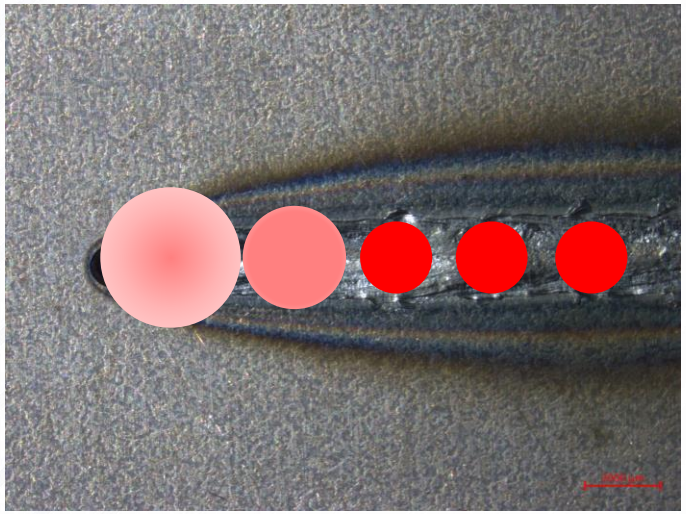
End

- Standard (hot start/cold end) linear power decrease at weld termination
- No cracking observed in linear welds
- Consistent depth to width ratio from start to end

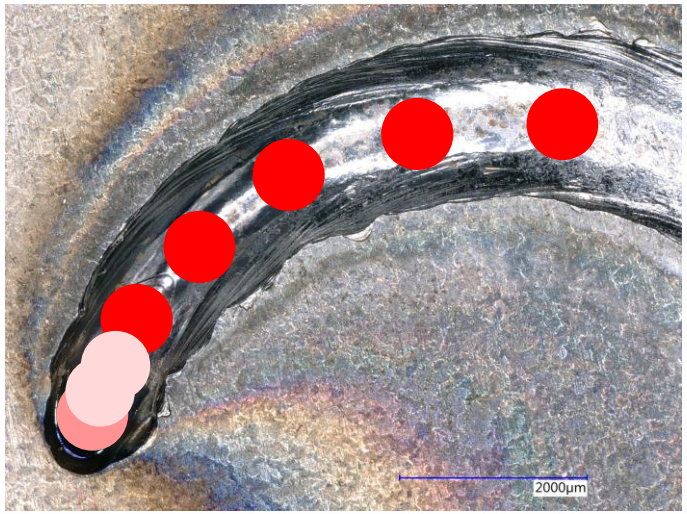
# WELD TERMINATION

Approach to mitigate centerline cracking in the weld termination

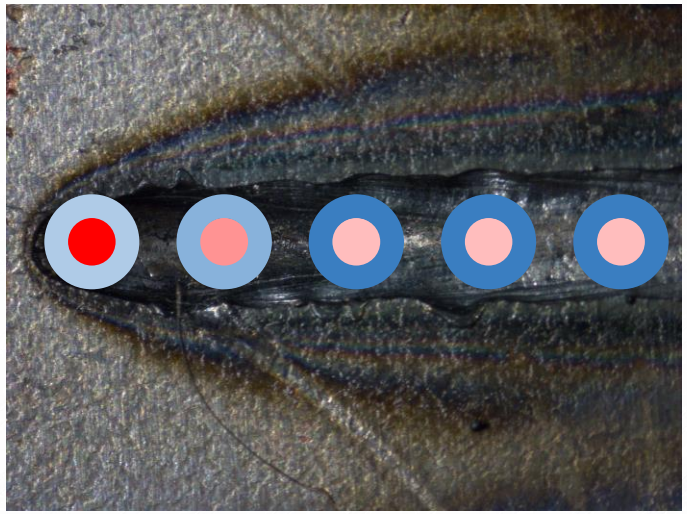
- Defocus = Increase the focal length which results in wider weld width at the surface with less penetration through the joint thickness.
- Lower Power Reverse = Secondary weld pass with minor laser energy.
- Independent power ramp =  Decrease power for the ring while simultaneously increasing power to the core.



Defocus

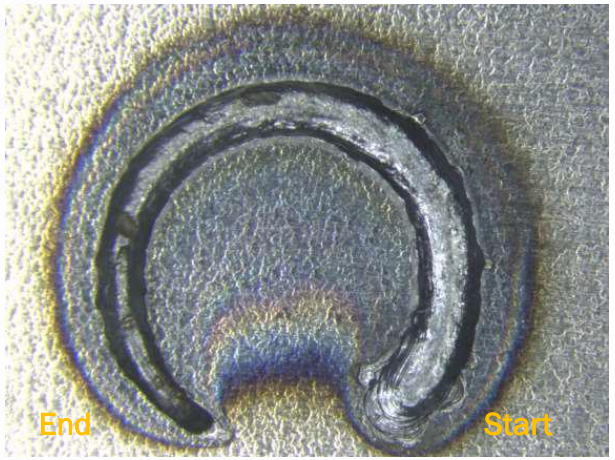
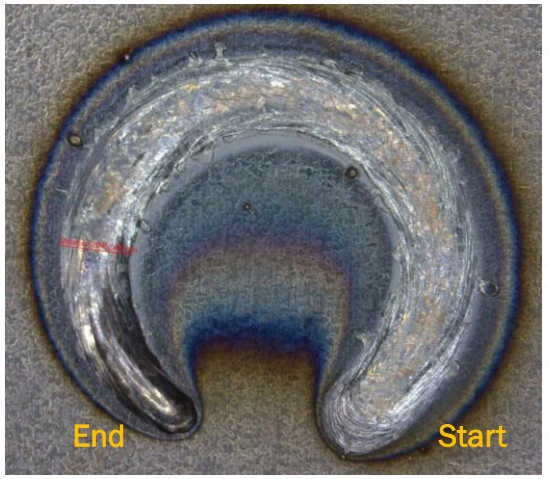
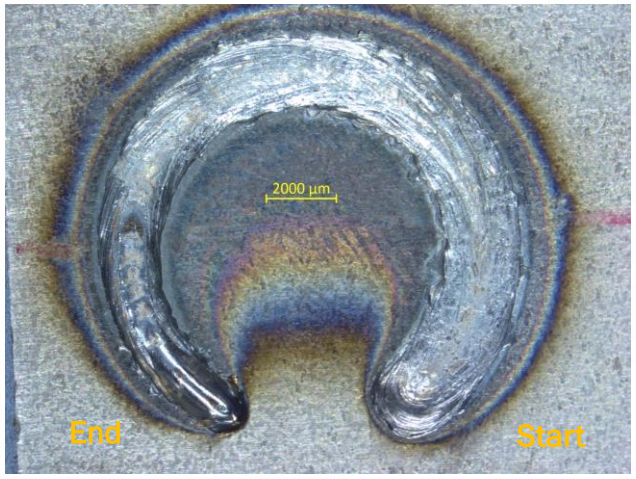
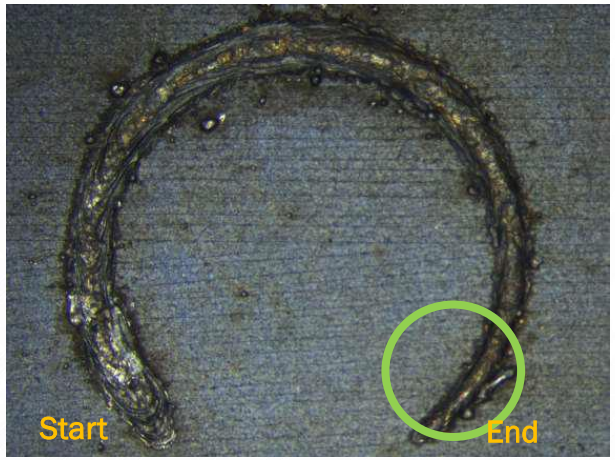
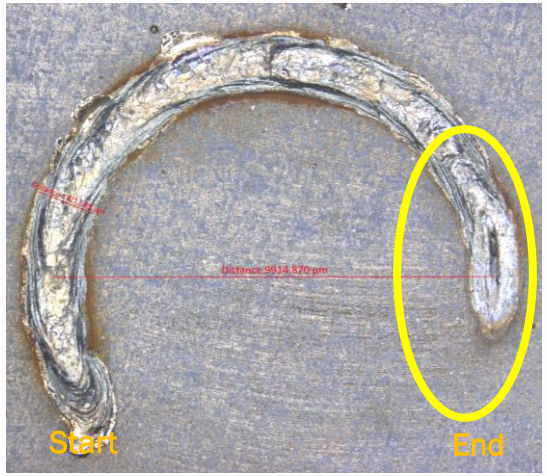



Low power reverse

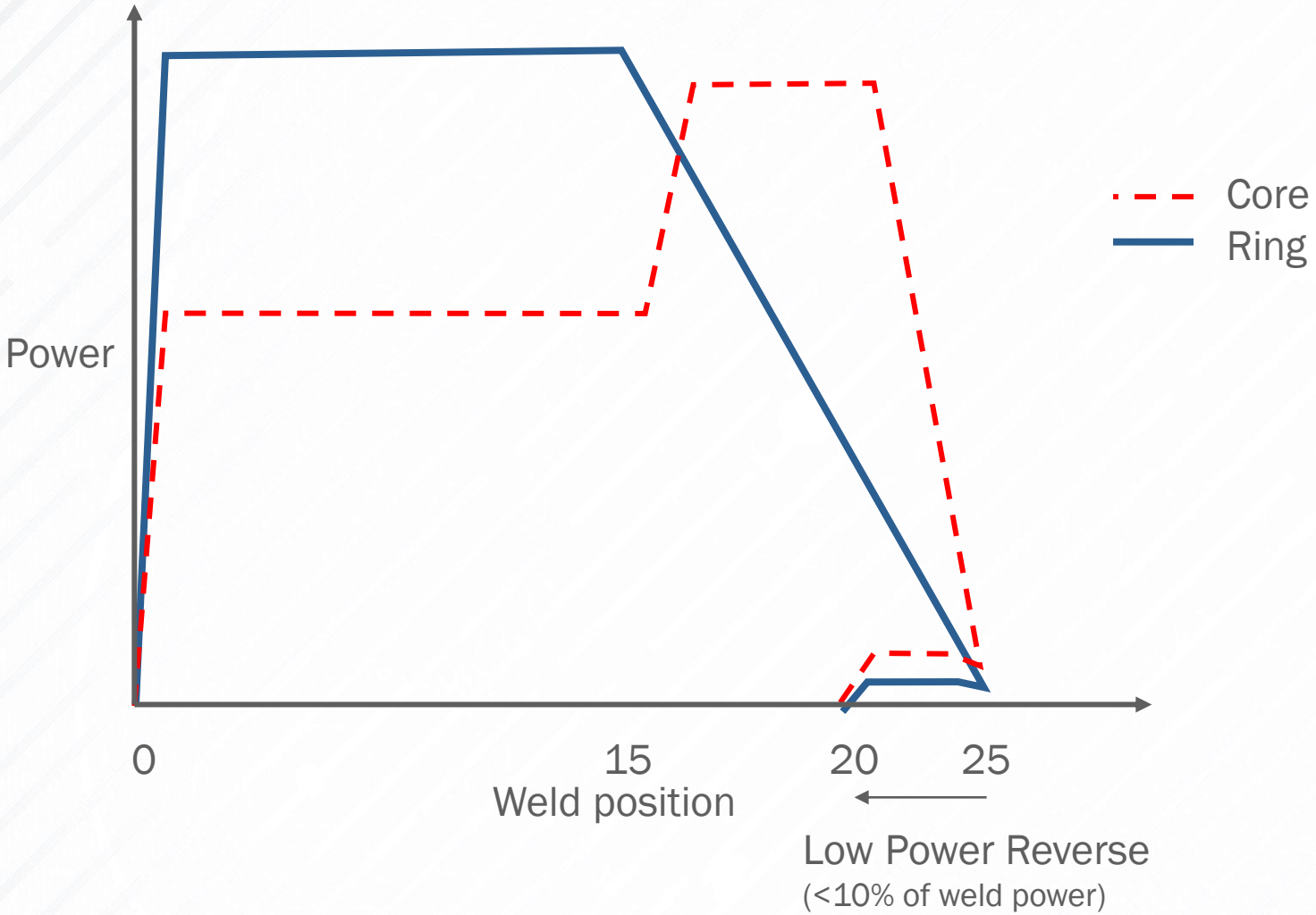


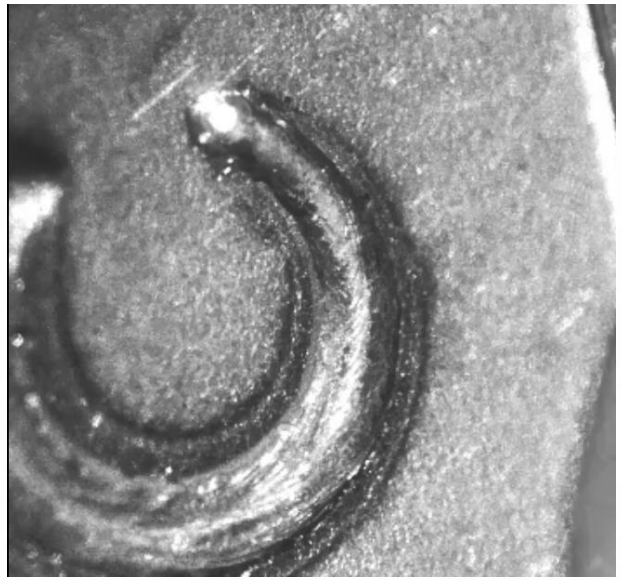
Independent power ramp

# CIRCULAR WELD

| | Baseline | Defocus | ✓ Independent power ramp and low power reverse |
|---|---|---|---|
| Top View |   |   |   |
| Bottom View |   |   |   |

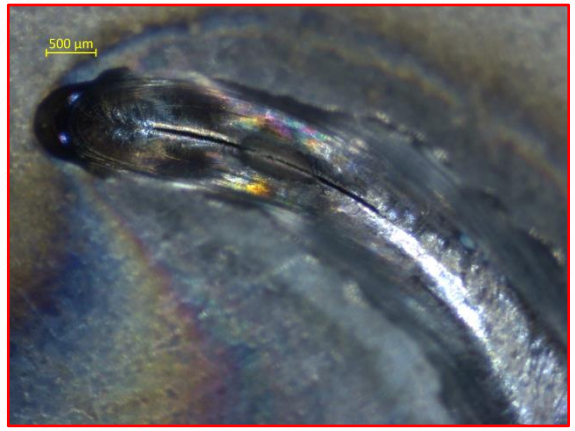
# WELD TERMINATION



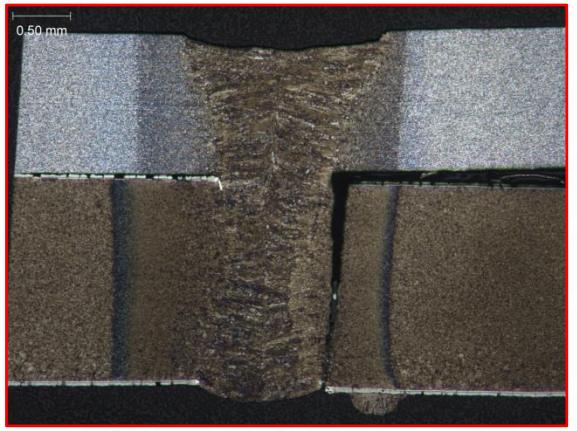



Independent power ramp and low power reverse mitigated the centerline cracking

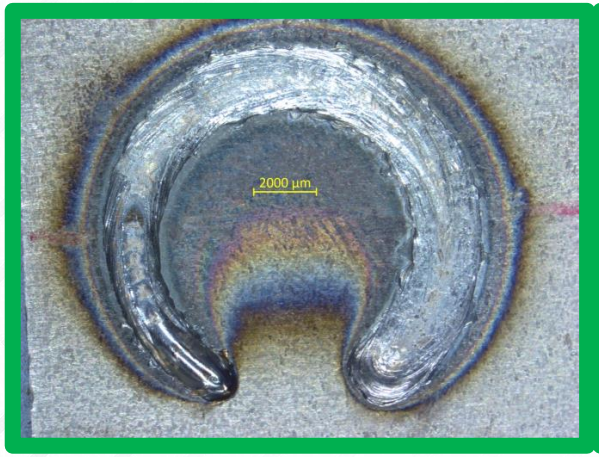
# CIRCULAR WELD- INTERMEDIATE RESOLUTION




Centerline crack




Through crack





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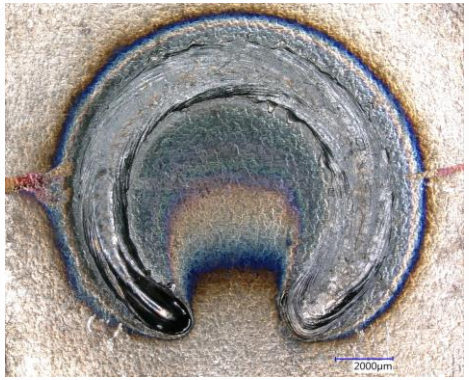
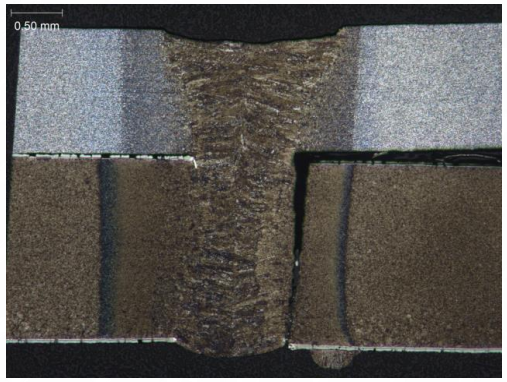
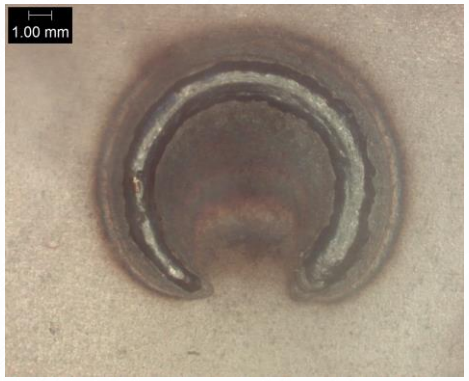
✓ Independent power ramp and low power reverse

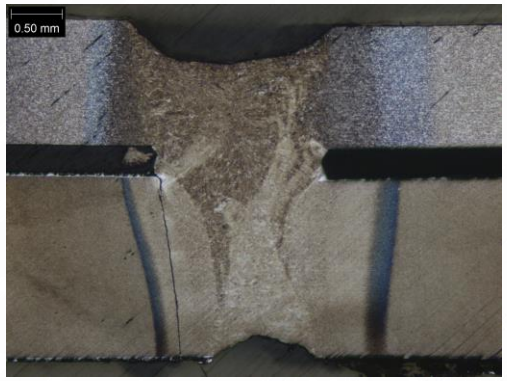
# CIRCULAR WELD - THROUGH CRACKS

- Through cracks were still present in circular welds
- Cracks occurred on the outer diameter of the circular weld in PHS2000



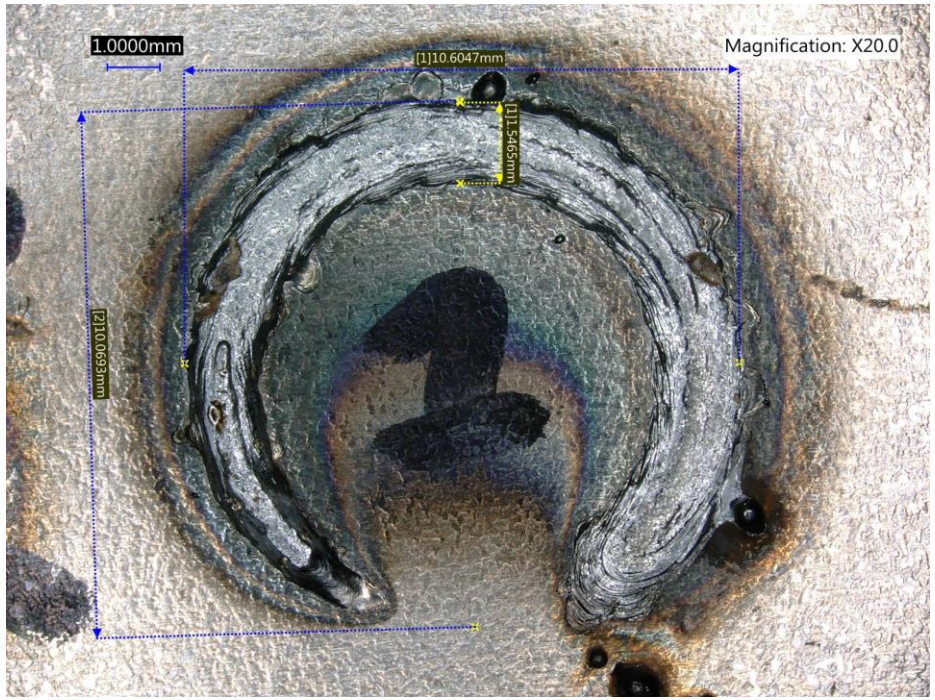

Theory:

- Inside cools down and shrinks slower than the outer weld boundary
- High energy stored in the center of the weld causing thermal stresses

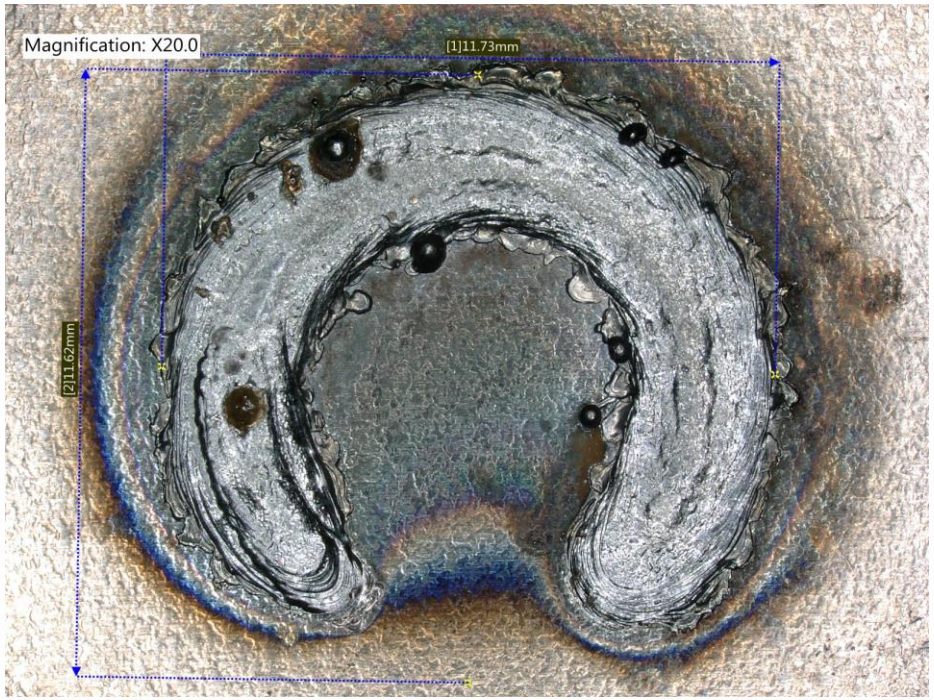
# CIRCULAR WELD - CRACK MITIGATION

Introduced laser beam oscillation to:

- Control the Heat Affected Zone (HAZ) on the outer boundary
- Increase the weld width (+48%)
- Reduce thermal stresses in the weld



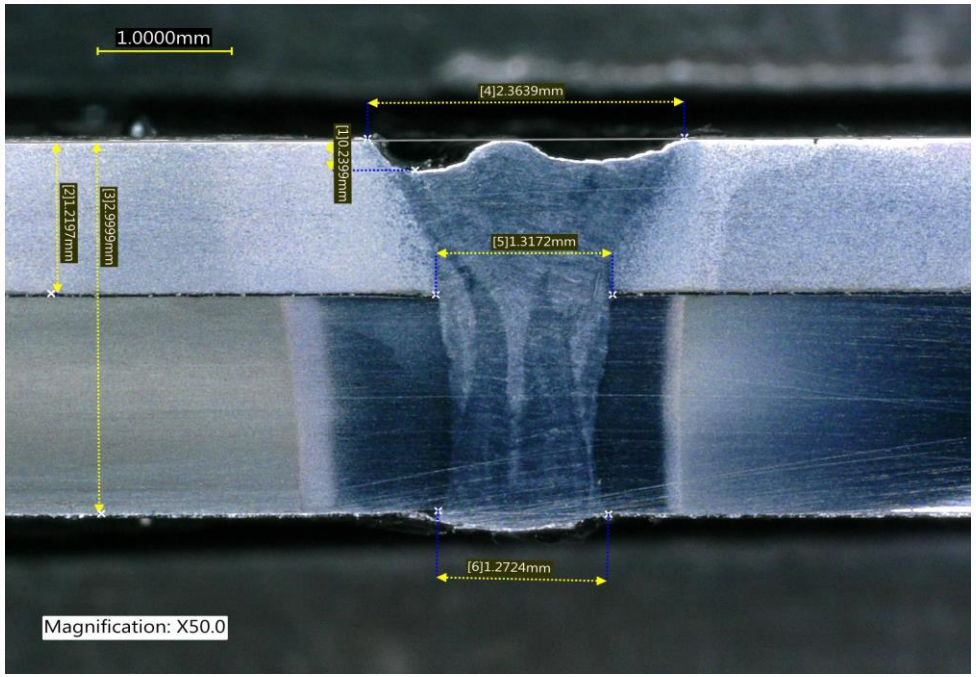

No wobble



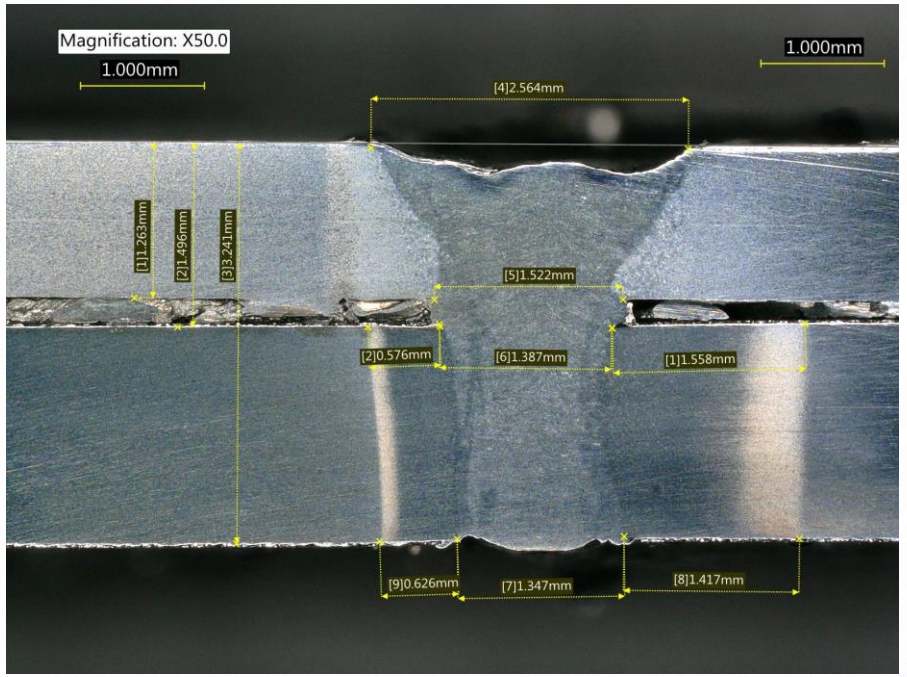

With wobble

# CIRCULAR WELD - CRACK MITIGATION

In addition, independent power modulation synchronized with oscillation was included to control the stored energy within the C-weld



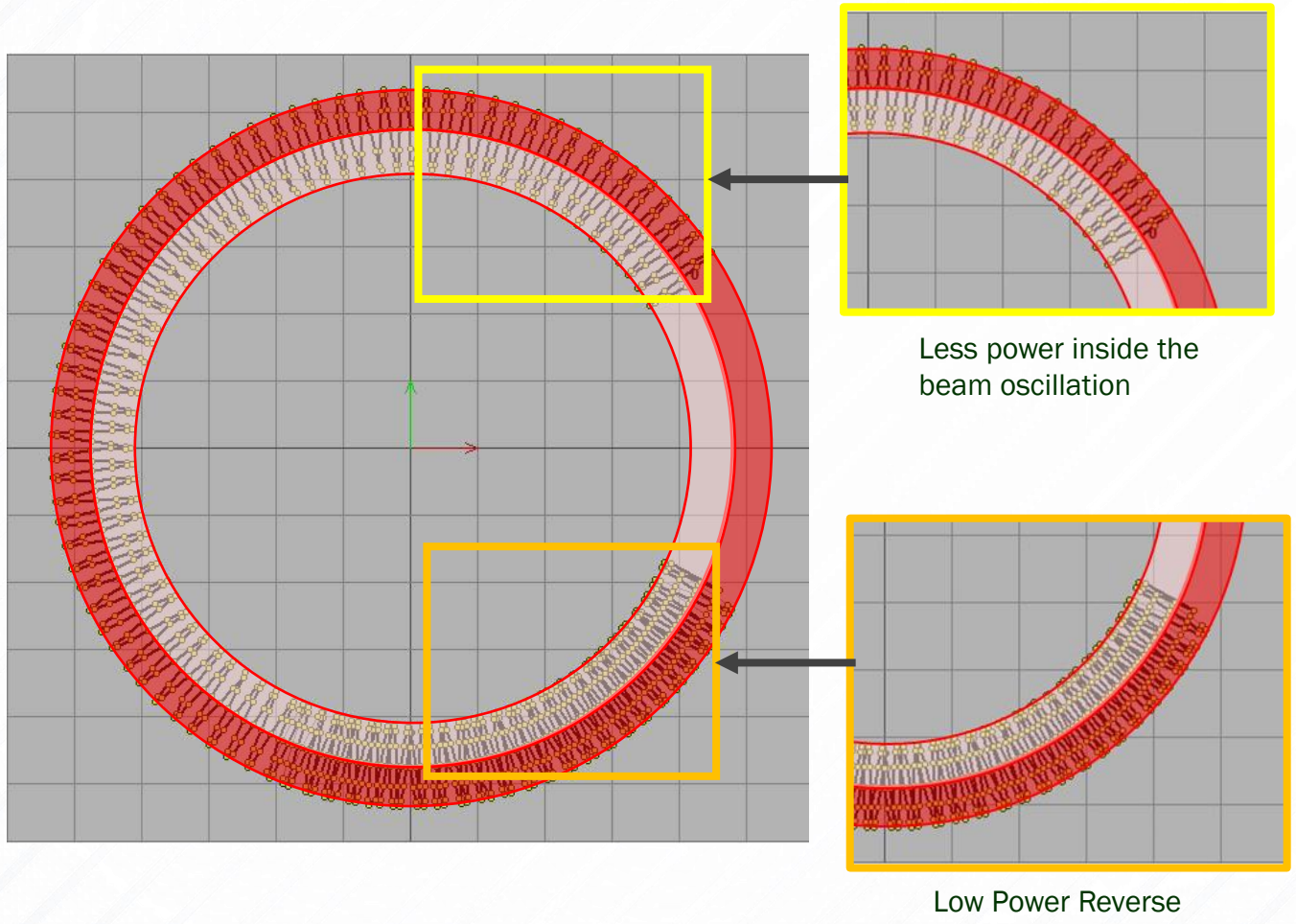

Zero Gap




0.3mm Gap

# CIRCULAR WELD - CRACK MITIGATION

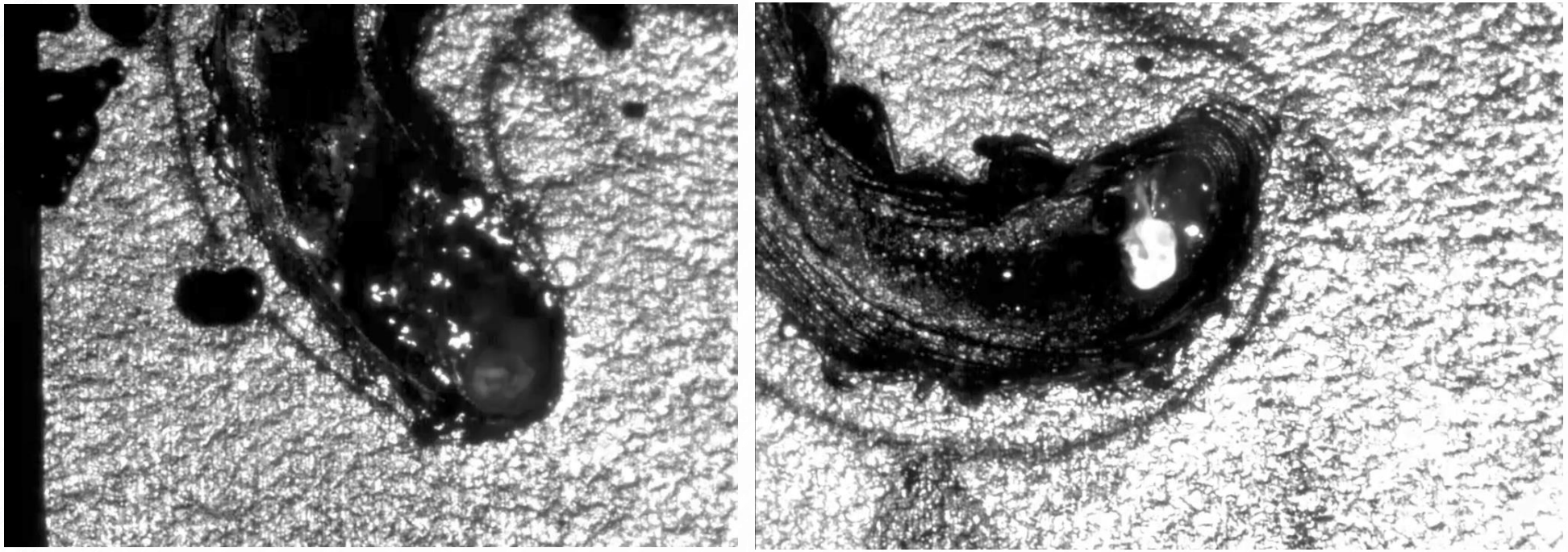
Independent power modulation synchronized with oscillation




The beam traces a sinusoidal pattern along the arc.
Laser power in ring and core are adjusted continuously from peak to peak to help
minimize heating of the area inside the weld zone and eliminate cracking.

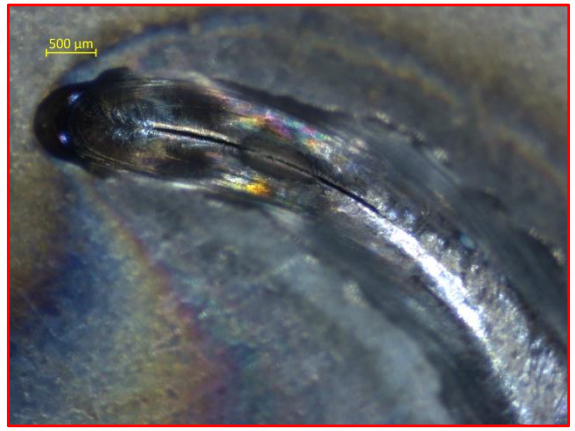
# CIRCULAR WELD- POWER MODULATION

Independent power ramp synchronized with oscillation and low power reverse

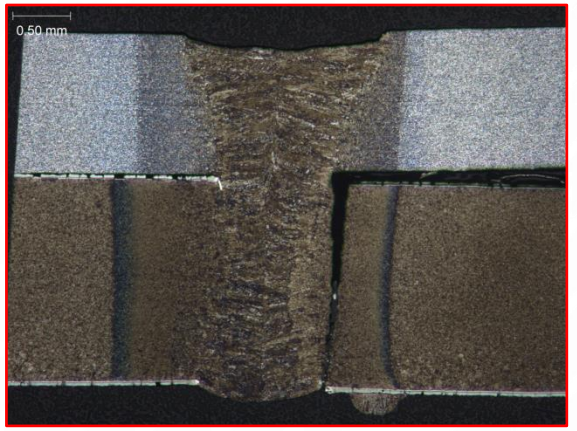


High Speed Camera of Synchronized Power Modulation

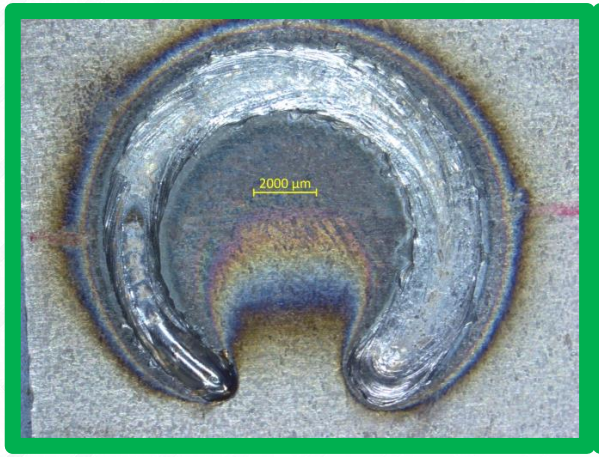
# CIRCULAR WELD- FINAL RESOLUTION



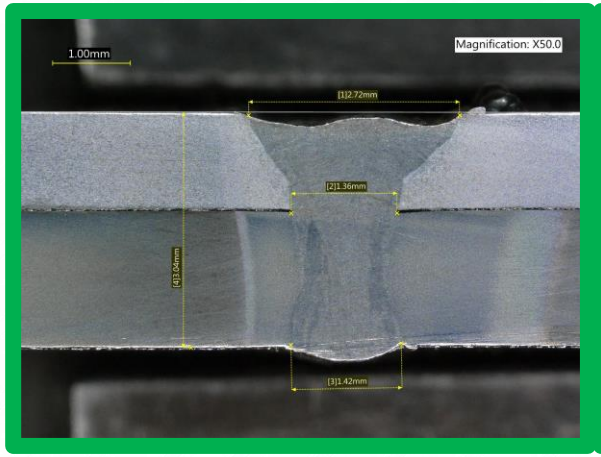

Centerline crack

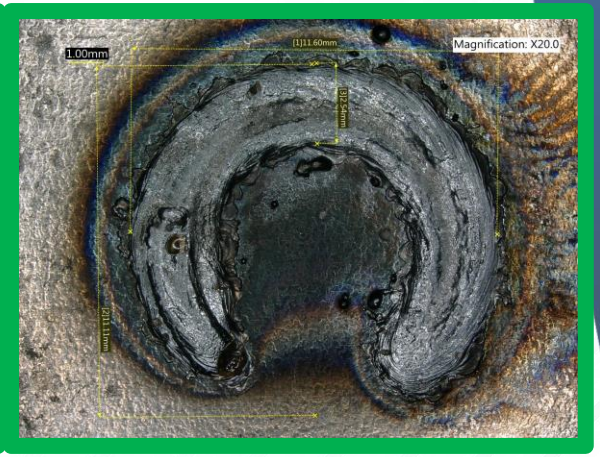



Through crack







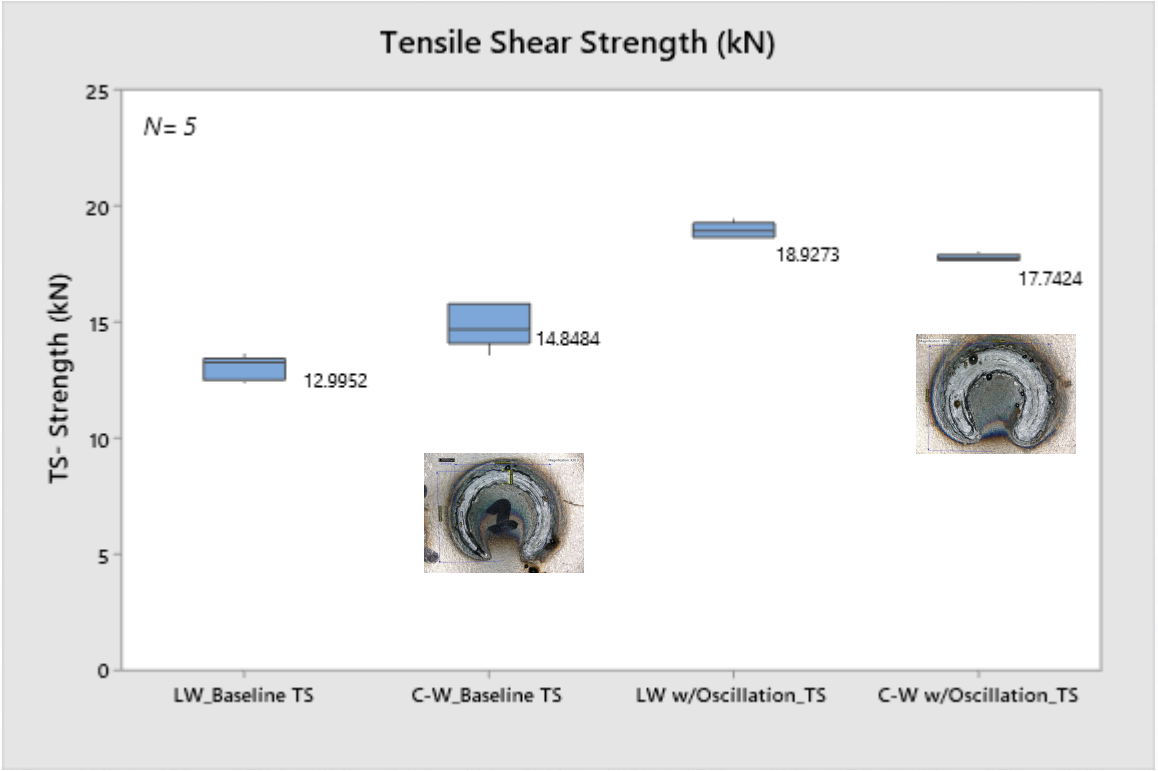

✓ Low power reverse + Independent power modulation + beam oscillation

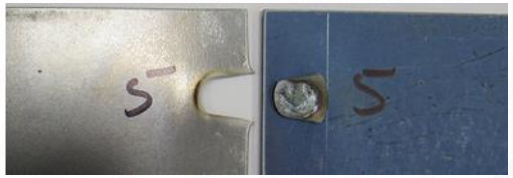
# WELD STRENGTH OVERVIEW

Tensile testing was performed for samples with and without oscillation for linear and circular welds.

Observations:

- The weld width increase from beam oscillation improves tensile strength performance (Linear +30%, Circular +16%)
- Fracture mode mainly occurred on top sheet base metal (DP600)

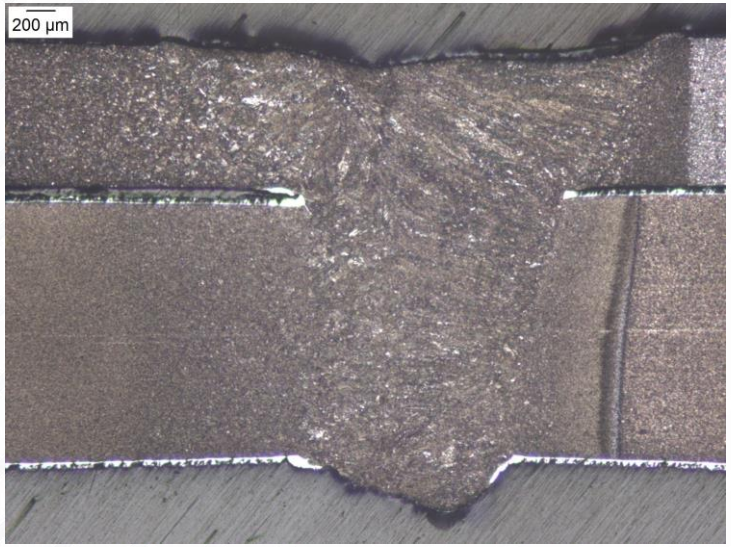



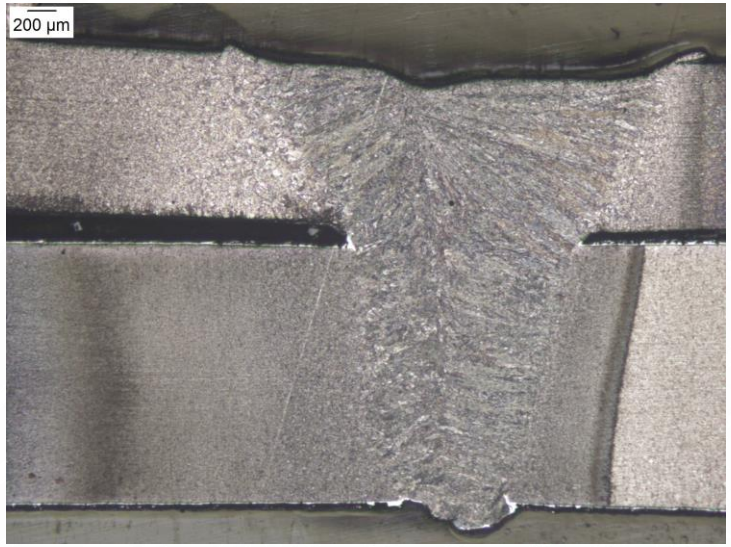
# PROTOTYPE INSIGHT

Coupon weld development was proven in prototype parts.
Different thicknesses were welded with same welding parameters.

- 1.6mm DP600
- 1.2mm DP600 - baseline
- 1.0mm DP600




1.0mm




1.2mm


1.6mm

**Identical weld parameters for all conditions**

# SUMMARY

- A mode shaping laser was used to successfully weld 600 MPa Dual Phase steel to 2000 MPa press hardened steel on coupons and prototype parts.
- Linear welds and circular welds had different crack behavior and required different welding strategies.
- Gap variation can influence the crack behavior.
- Low Power Reverse was used to avoid cracks in the weld termination.
- Laser beam oscillation combined with power modulation was used to avoid through cracking in the weld.

# FOR MORE INFORMATION

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