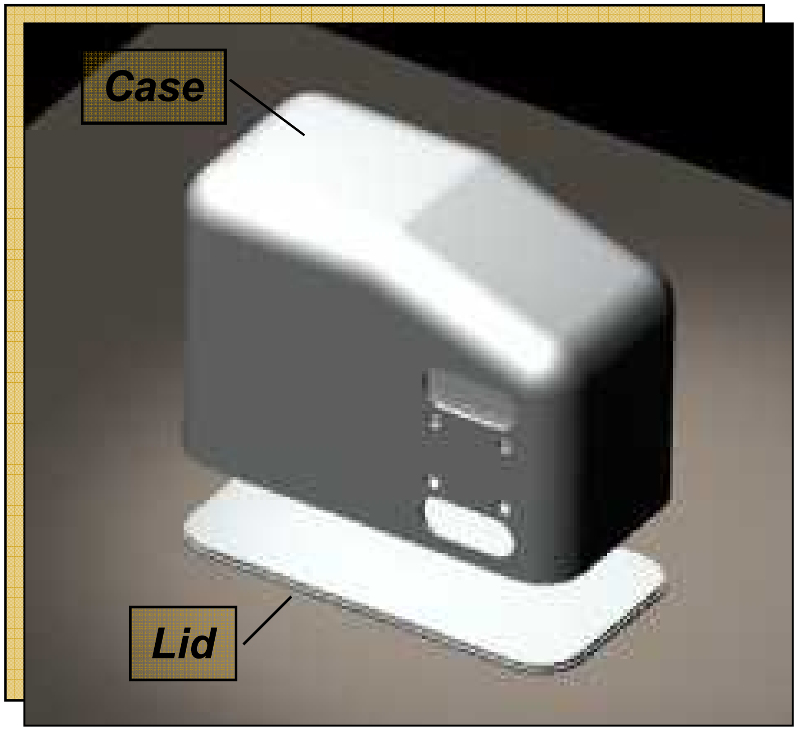
SAND2007-1538C

Joining Capability Analysis for ELNG Structure



Welding Team:

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Goal – 1st year

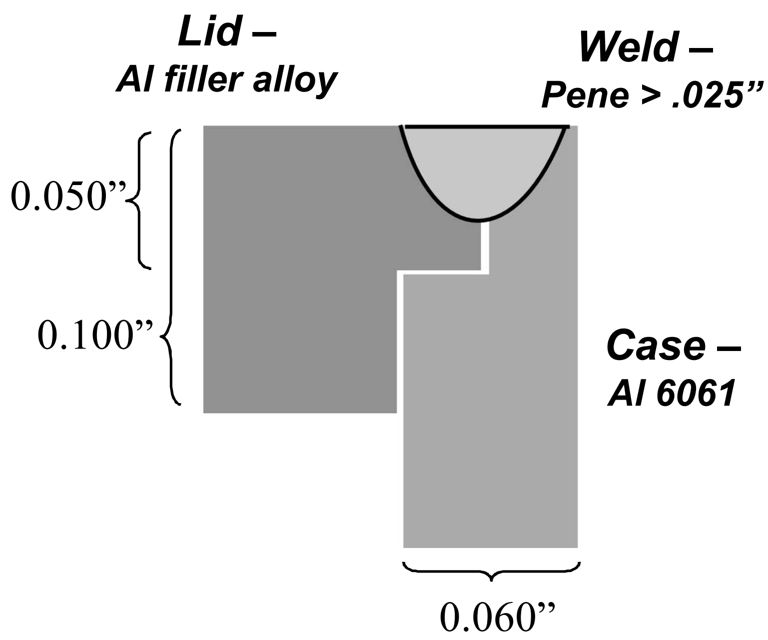
- Conduct weld process and materials compatibility analysis to meet design requirements for the ELNG case and lid closure weld

Approach

- Determine design requirements; utilize current modeling capabilities for penetration assessment
- Identify possible materials combination (case and lid) and welding processes
- Investigate joining capabilities and limitations
- Evaluate weld process vendors
- Determine best weld process and material combination using a decision analysis

Weld Requirements

- Design Requirements
  - Penetration minimum 0.635 mm (0.025”) for partial penetration weld.
  - Low heat input to avoid damage to internal hardware
  - Under flush or flush / no convexity
  - No appreciable joint distortion
  - Non-hermetic
- Quality Requirements
  - No cracks
  - Minimize porosity
  - Even weld bead appearance; minimal blowholes
- Other
  - Eliminate need for chemical deoxidizer



“Requirements” focus material and weld process selection

Possible ELNG Materials

Materials

- Electro-formed Ni case:
  - Cases produced did not meet the drawing requirements
    - Team decided not to pursue
- Aluminum alloy case:
  - Known compatibility with attachments and surrounding material
  - 6061-T6 Al has high propensity for solidification cracking when welded
  - Use of filler alloy (i.e. Al 4047) for the lid will reduce crack tendencies
  - Al 4047 filler alloy is difficult to obtain in sheet form
  - Typically requires chemical deoxidizing prior to welding
- Stainless Steel alloy case:
  - No previous history therefore not under investigation at this time

Material Combinations to be Investigated

Al 6061-T6	**Al 4047-1**
Al 6061-T6	**Al 5083-H116**
Al 6061-T6	**Al 5456-H116**
Al 6061-T6	**Al 6061-T6**

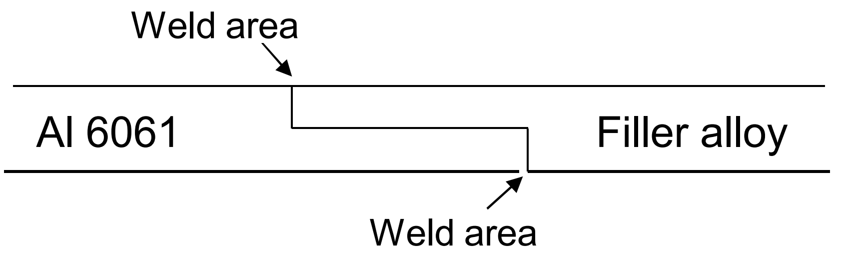
Possible ELNG Welding Processes

Weld Processes

- Laser Beam Welding (LBW): High irradiance allows for weldability through oxide layer and provides minimum heat input
  - ➢ ***Continuous Wave*** – capable of high speed welding.
  - ➢ ***Pulse Modulated*** – capable of high speed welding with reduced heat input
  - ➢ ***Pulsed*** – very low heat input and good weld aspect ratio control
  - ➢ ***Pulse Shaping*** – may reduce weld defect occurrence
- Arc Welding: Lower solidification rate reduces crack tendencies however requires more heat input than LBW
  - ➢ ***GTAW (DCEN)*** – less prone to solidification cracking; increased heat input.
  - ➢ ***PAW (DCEN)*** – less prone to solidification cracking; reduced heat input
  - – ***Variable Polarity Arc (PAW or GTAW)*** – offers cathode etching of oxide layer allowing for improved fluidity, offers good weld aspect ratio control, and is less prone to cracking
- Other:
  - – ***Friction Stir*** – new process typically used for larger scale welds. Micro friction stir is currently undeveloped

Evaluation of Weld Processes

Test Sample Design:



Welding equipment selection:

- 5 laser welder manufacturers (both CW and Pulsed Nd:YAG)
- 1 friction stir welder manufacturer
- 1 VPPAW manufacturer

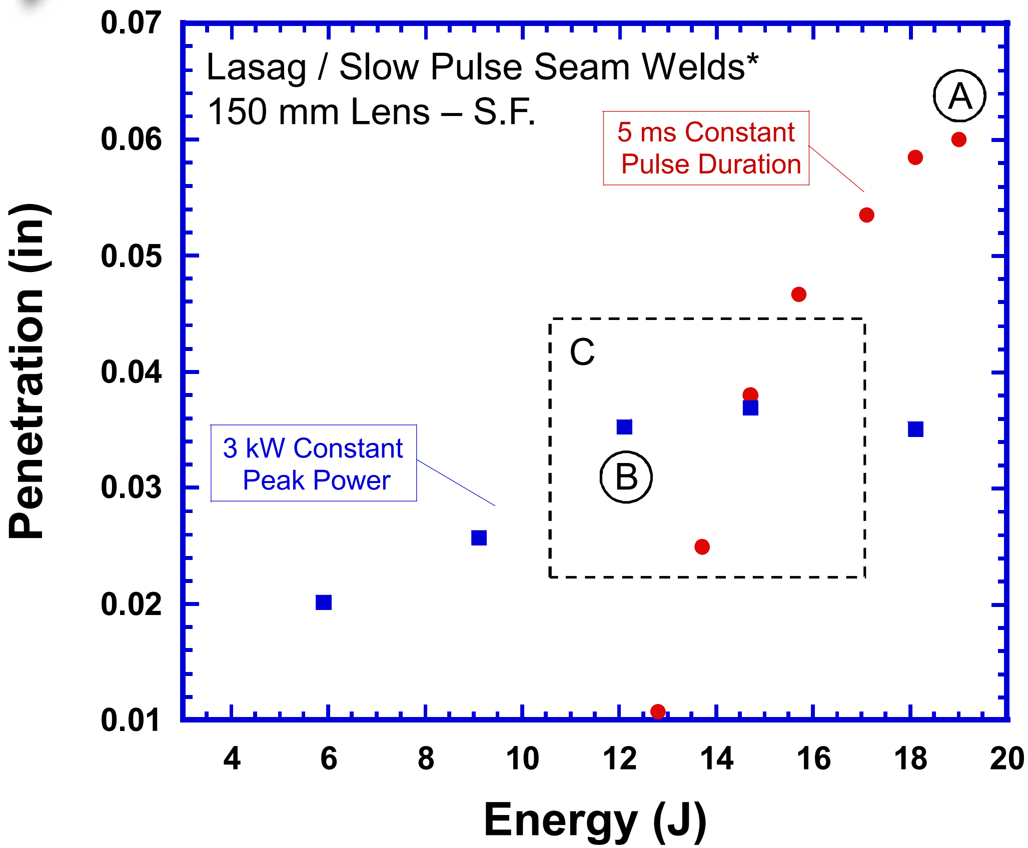
Perform weld process and material compatibility analysis through DOE's, metallographic sectioning and radiographic x-ray to:

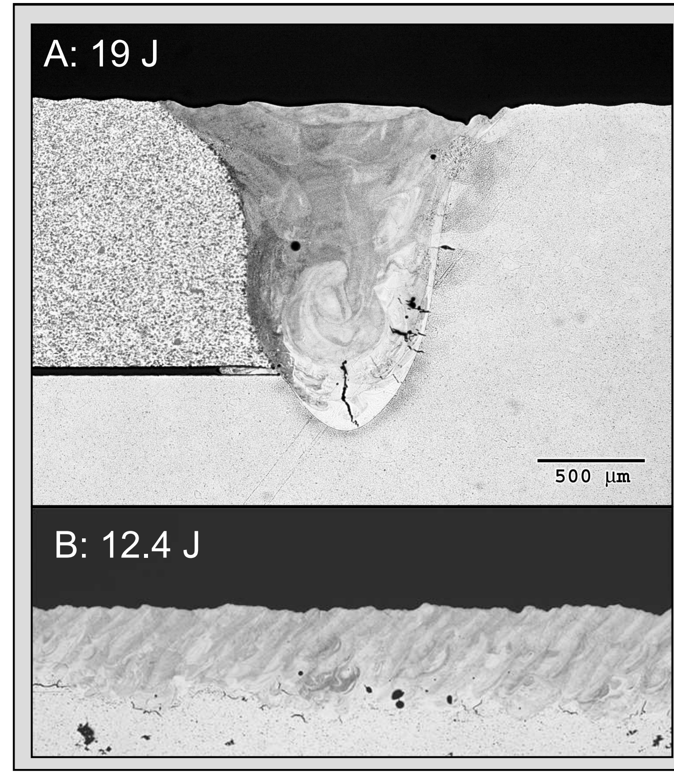
- identify functional weld parameters
- Evaluate mechanisms which drive weld defects such as cracking, blowholes, porosity, etc.
- Quantify defect propensity for each process and selected materials

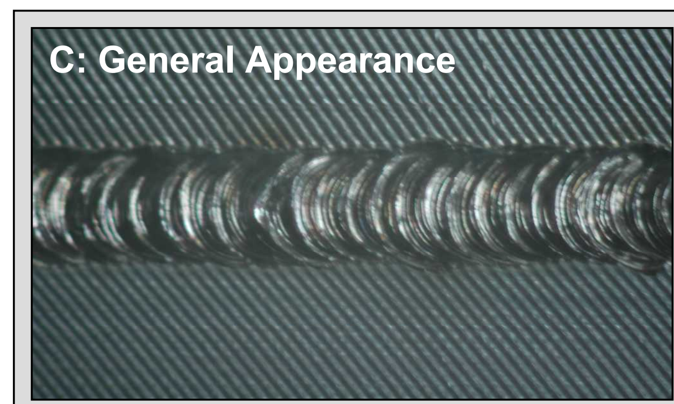
National Nuclear Security Administration

Sandia National Laboratories

Weld Evaluation: Joining of Al 4047 to 6061



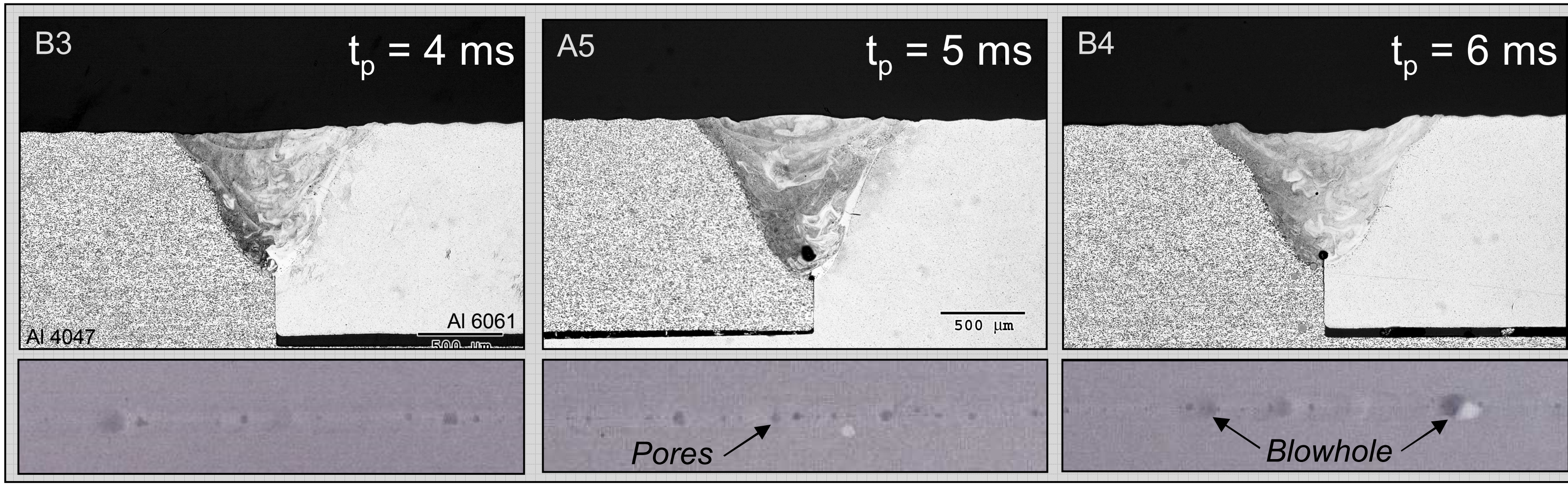




- Increased overlap needed to reduce penetration variation
- Liquation cracking tendencies even at lower penetrations (0.025”)
- No visible surface cracks

*Not all points shown

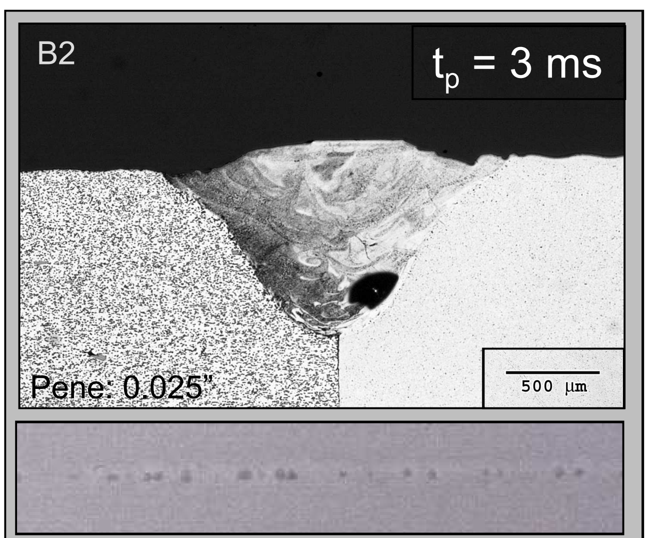
Weld Evaluation: Joining of Al 4047 to 6061



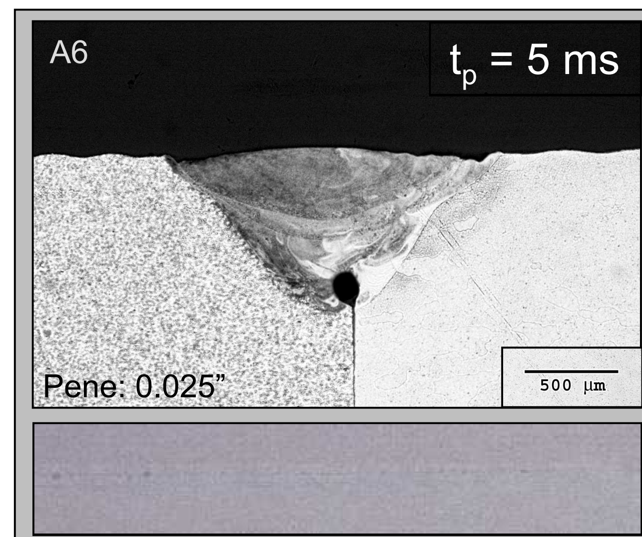
12 J, 3 kW
Pene: 0.035”, A: 0.0008 in^2

15 J, 3 kW
Pene: 0.038”, A: 0.0010 in^2

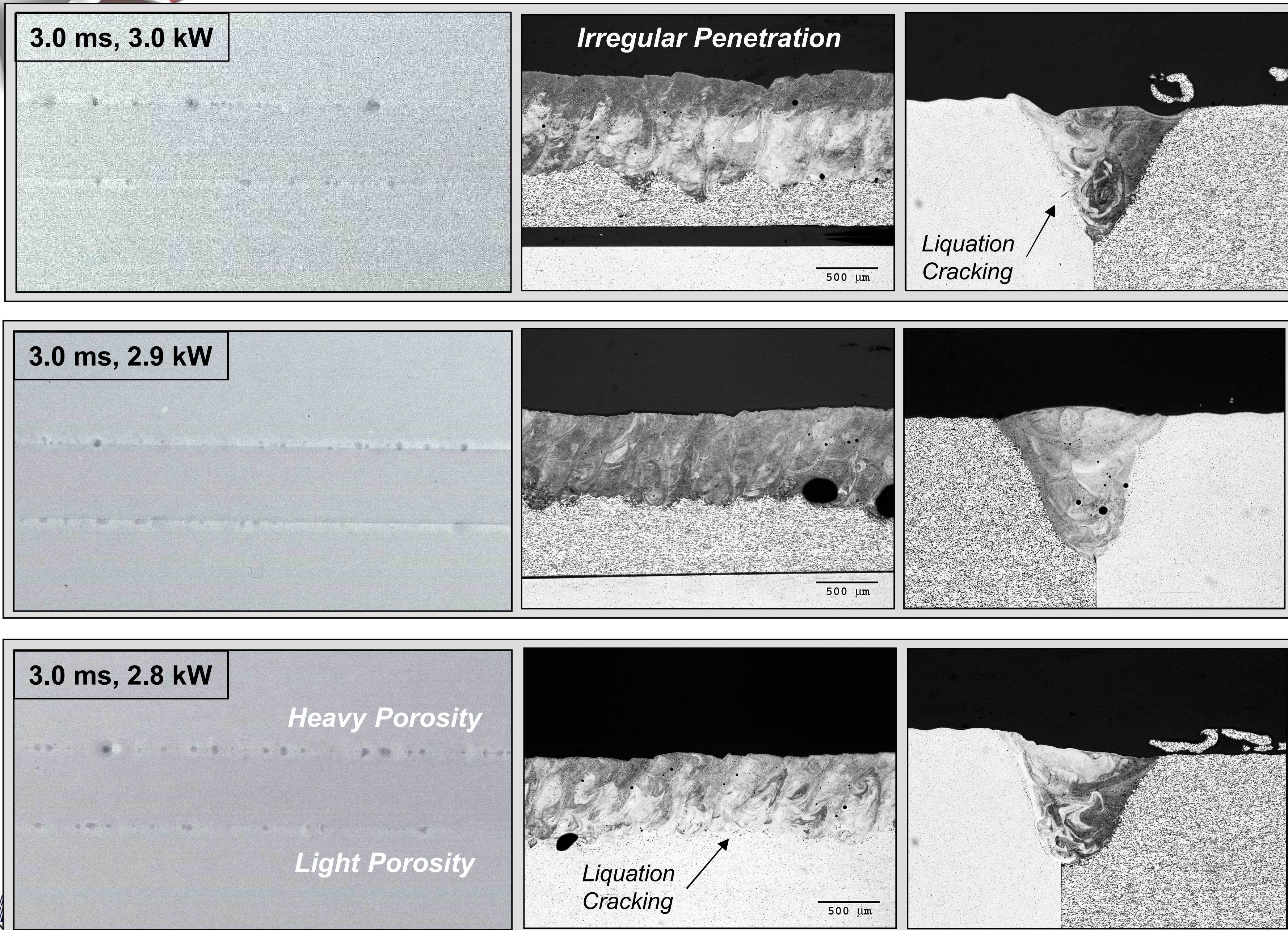
18 J, 3 kW
Pene: 0.035”, A: 0.0009 in^2



- Cause of pore formation not certain; presumed chaotic.
- Occurrence of periodic blow holes is unknown.
- Meets all design requirements

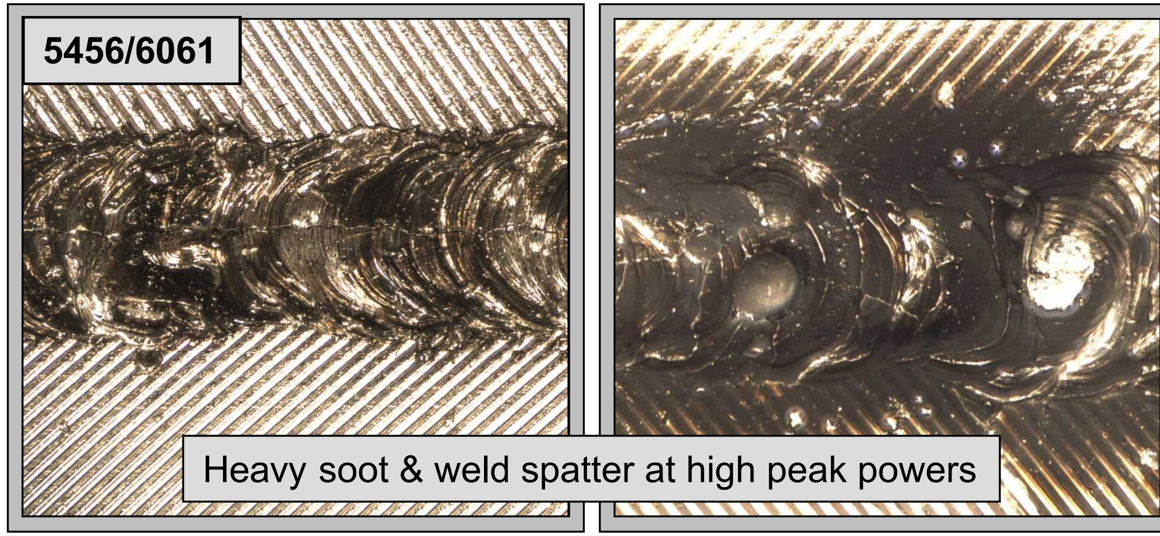


Miyachi Unitek: Pulsed Nd:YAG



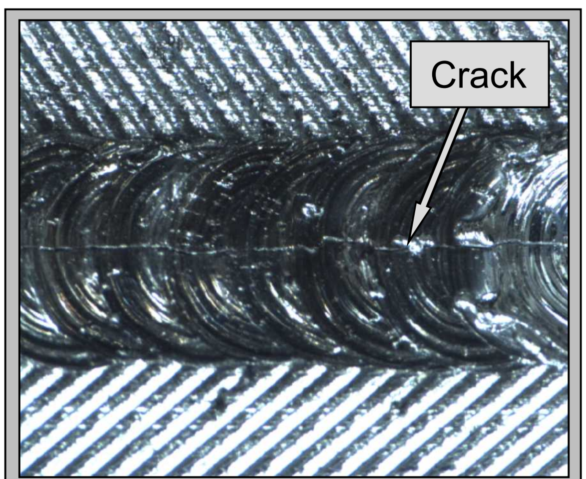
Weld Evaluation: SNL Pulsed Nd:YAG

- Heavy soot, presumably magnesium, observed for all test conditions. Cleanliness may be of concern/problematic
- Prominent centerline cracking.
- Large penetration variation; 0.010” for a 0.030” deep weld
- Fractography revealed heavy porosity

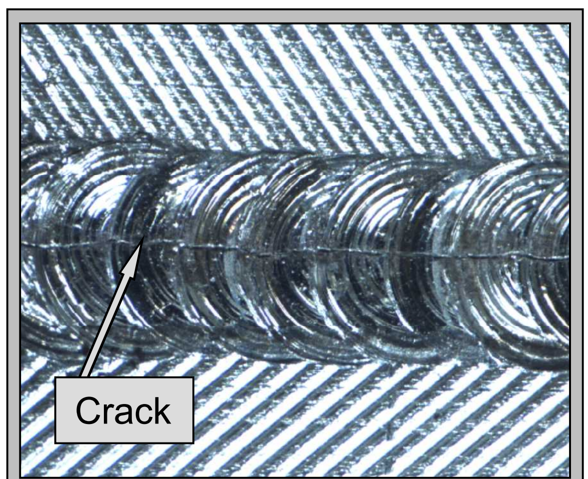


AA4 – 2740 W

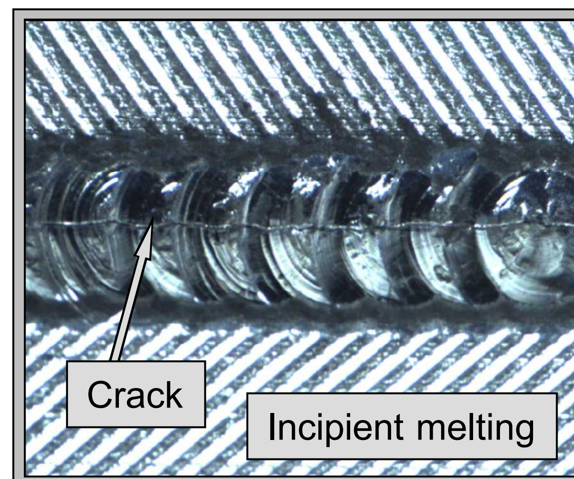
AA1 – 3800 W



AA5 – 2380 W
W_{weld} ~ .040”



AA6 – 2140
W_{weld} ~ .035”

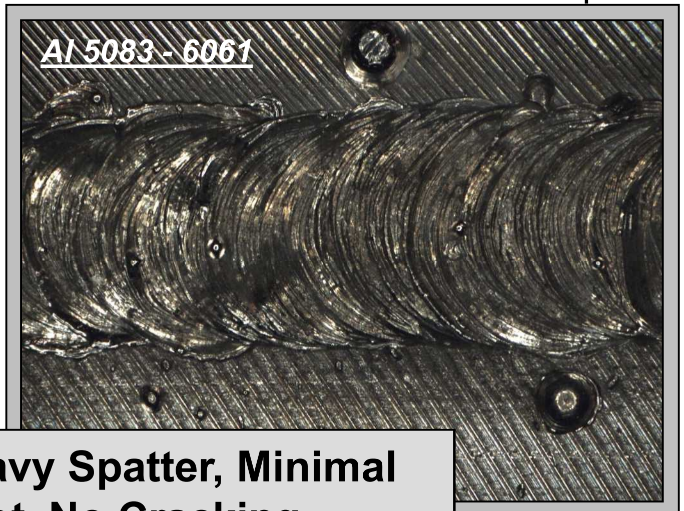


AA7 – 1940 W
W_{weld} ~ .025”

*** Images are Al 5456 to 6061. Consistent behavior when joining Al 5083 to 6061.**

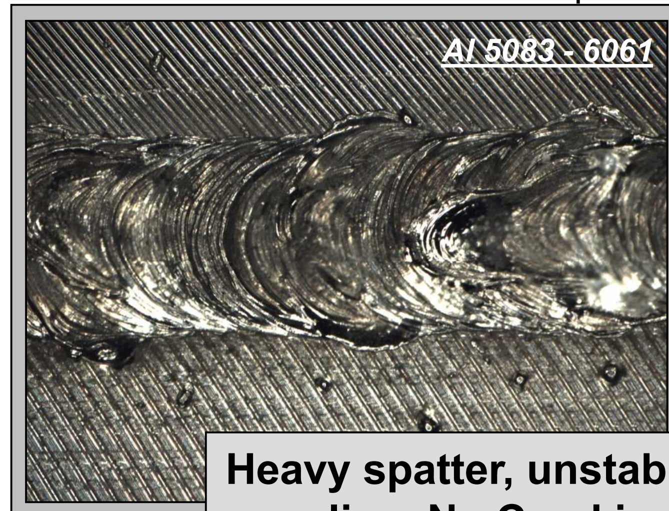
Weld Evaluation: SNL-Rofin CW Nd:YAG

BB1 – 1205 W / 1450 J/in / 50 ipm



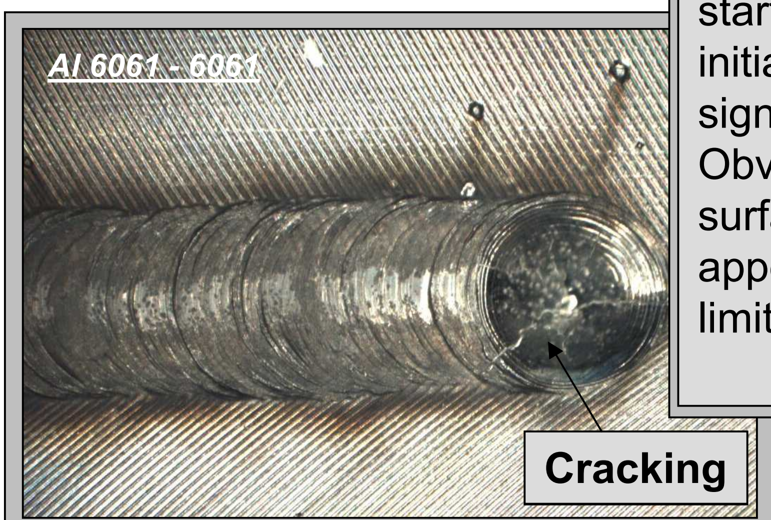
Heavy Spatter, Minimal Soot, No Cracking

BB2 – 1205 W / 900 J/in / 80 ipm



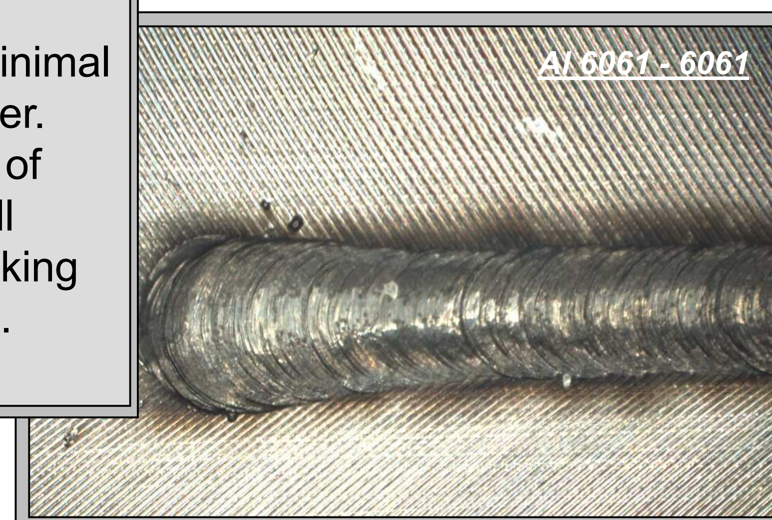
Heavy spatter, unstable coupling, No Cracking.

CE1 – 1205 W / 2400 J/in

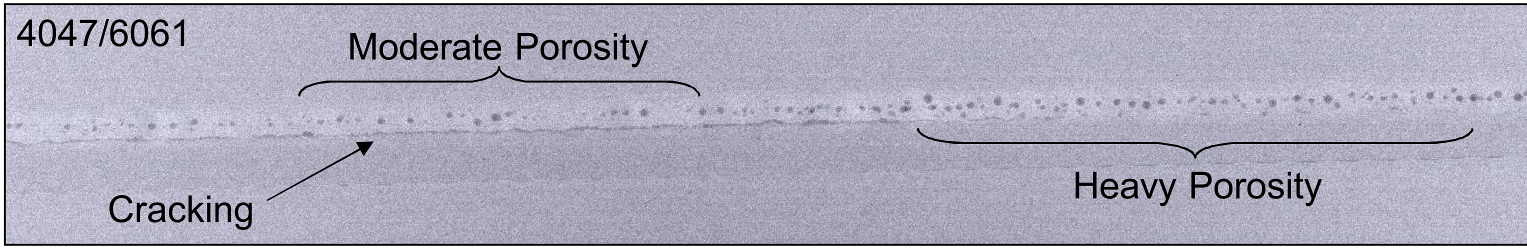


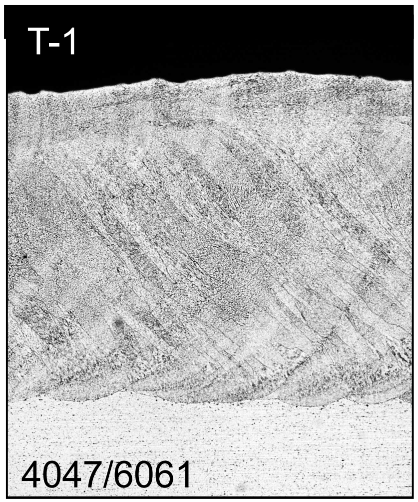
Dwell necessary at the start of welding to initiate coupling. Minimal signs of weld spatter. Obvious formation of surface oxides (dull appearance). Cracking limited to weld end.

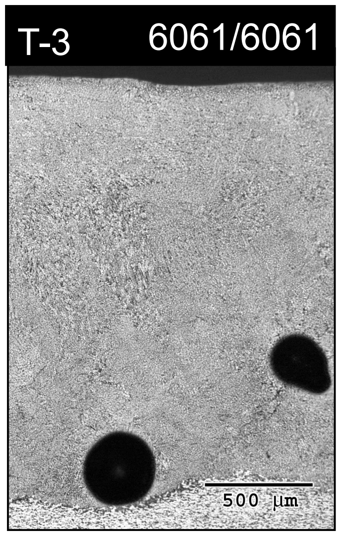
CE2 – 1205 W / 1450 J/in



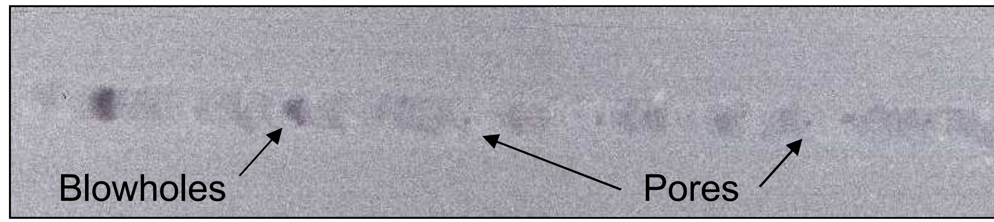
Weld Evaluation: Trumpf CW Nd:YAG

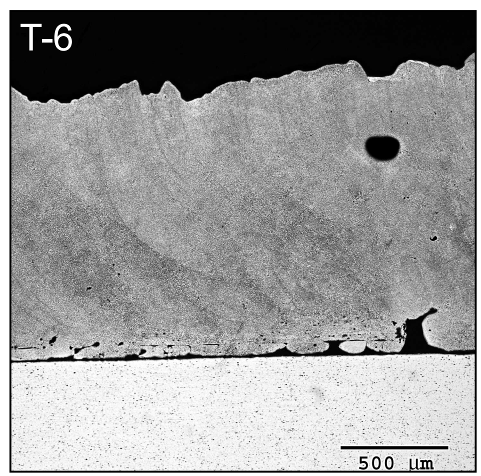


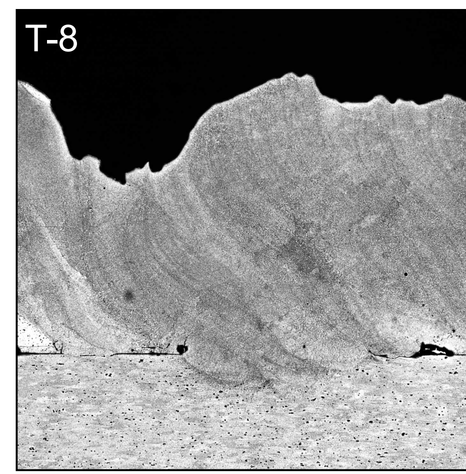




<u>Al 5083 to 6061: 1000 W @ 40 ipm:</u>





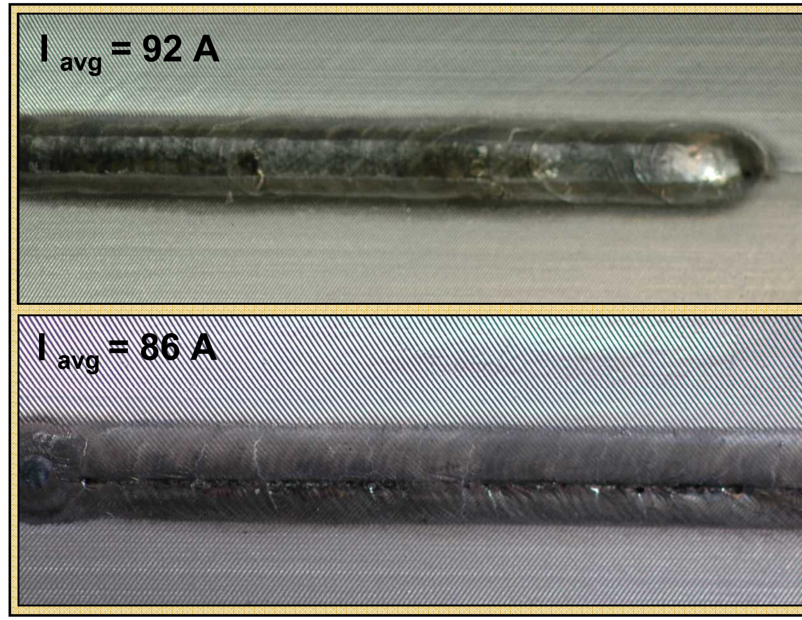


- Severe liquation cracking and irregular porosity for 4047 to 6061 joints
- Increased penetration with 4047/6061over that of 6061/6061
- Inconsistent coupling resulting in blowholes and surface irregularity for 5000 series alloys

- Pores not as prevalent in 5000 series samples

Weld Evaluation: Arc & Friction Stir Processes

- DCEN GTAW & PAW
  - Both required very high heat input to brake through oxide layer
  - At reduced heat input, oxides greatly hampered fluidity
  - No visible surface cracking for 4047/6061
  - Required helium pilot gas (PAW)



- VP PAW
  - Weld samples being performed by Liburdi Dimetrics Automation Inc.
  - PAW allows for increased weld aspect ratios with greatly reduced heat input
  - Cathode etching removes oxide layer promoting better fluidity and pore reduction

- Friction Stir Welding
  - Weld samples prepared by AccuStir – General Tool Co.
  - Weld evaluation and process capabilities are under investigation

Summary & Future Work

- Based on defined requirements for the ELNG case and lid closure weld:
  - Al 6061, 4047, 5083, and 5456 were chosen as to be investigation
  - LBW, arc welding and friction stir were identified as possible weld processes
- LBW capabilities:
  - Pulsed Nd:YAG proved to meet <u>all</u> requirements for a 4047/6061 material combination
  - Porosity was prevalent however unrepeatable in all 4047/6061 welds
  - No surface cracking were observed in 4047/6061
  - 5000 series Al was not weldable with the pulsed YAG process due to severe cracking and heavy soot
  - CW welded all Al alloys however required very high powers and resulted in extreme liquation cracks
- Arc Welding Capabilities:
  - DCEN could only weld Al at very high current without the use of a chemical deoxidizer
  - Oxides greatly hampered fluidity in the joint
  - VPPAW weld samples are still being evaluated but current information/results show high a capability.
  - Al is highly weldable through VP cathode etching
- Friction Stir Capabilities:
  - Successfully welded all Al samples
  - Compatibility to current joint design is under review

Summary & Future Work

- Conclude evaluation of vendor weld samples
  - Eliminate processes that don't meet design and quality requirements
- Conduct decision analysis of material, equipment and vender attributes
- For the chosen process and material(s), further compatibility study to include real parts and the specific joint design
- Address other ELNG joining issues
  - Solder joints
  - Laser spot welds
  - Materials