SAND2008-5798C

Welding of Al 6061 to Al 4047 For Electronic NG Container

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History

- It has been over 10 years since the last Electronic Neutron Generator (ELNG) was manufactured.
- The manufacturing plant was in Florida.
- At present Sandia lacks the capability to manufacture the ELNG.
- We have the opportunity to advance technology, make drawing changes, and ready the product for production.

Opportunities for Change

- Incorporate lean 6 sigma principles
  - Small production numbers
  - Limited number of years in production
  - Ask the 5 whys
- Design for manufacturability and assembly
- Document findings – populate the “Tool Box”

Procedures

- Review drawings and requirements
  - Challenge unreasonable specifications
  - Model component
- Conduct a literature search
  - Weldability of materials – What are my material choices?
  - Processing options – Research new welding processes
  - Options for manufacture of container and cover

Procedures

- Create inexpensive test samples
  - Send samples to the application laboratories of various equipment manufacturers
  - Evaluate welds from each processing option and material type
    - Visual examination
    - X-ray examination
    - Longitudinal and cross sections of weld
- Choose optimum weld process and equipment

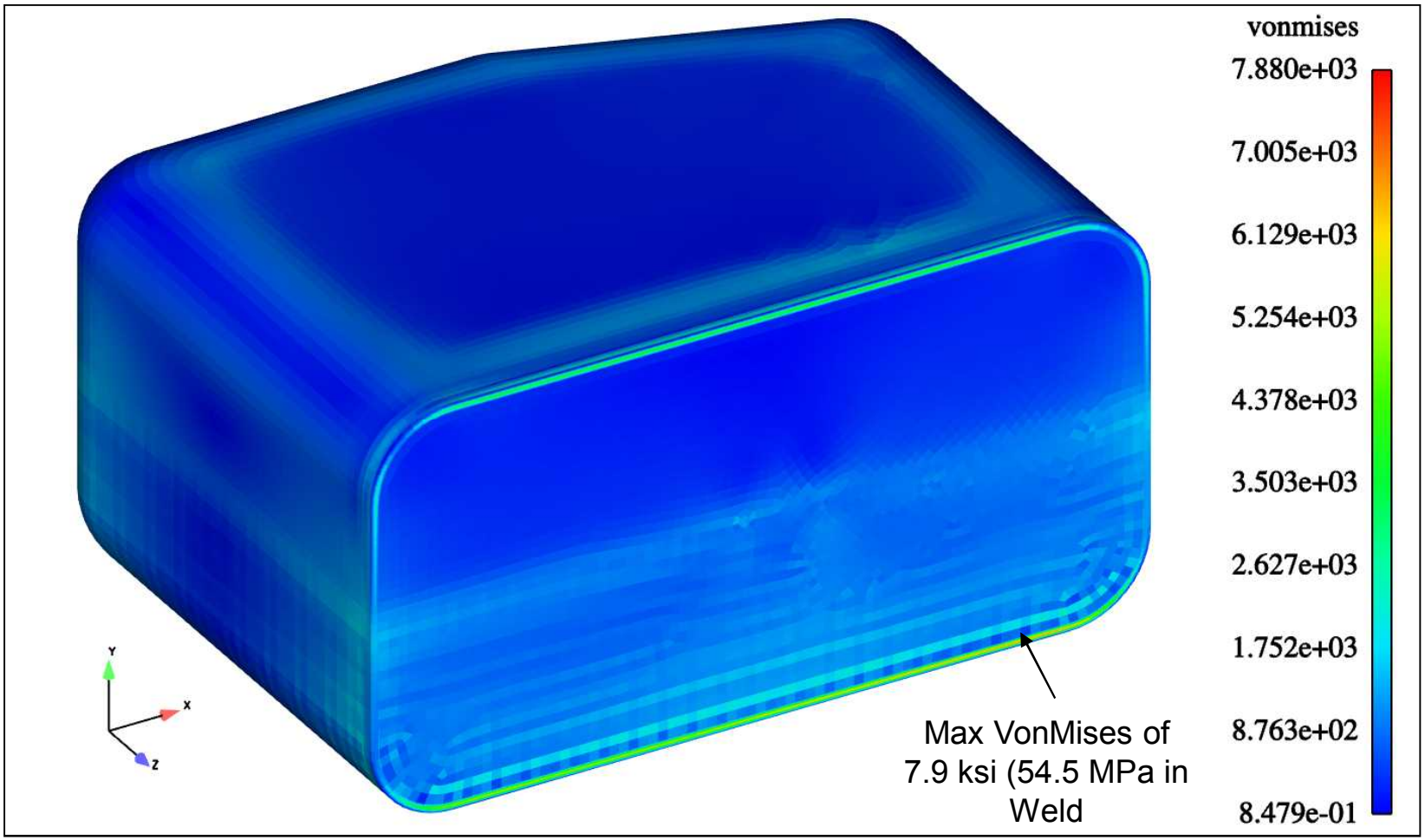
Review Drawings and Requirements

- Partial penetration weld required
- Weld to be flush or underflush
- Container to be hydroformed and the cover to be machined
- Electron Beam Welding
- Material
  - Al 6061 – High strength aluminum (container)
  - Al 4047 – Typical filler metal for Al 6061 (cover)
- 0.050” (1.27 mm) penetration
  - Need to verify through modeling

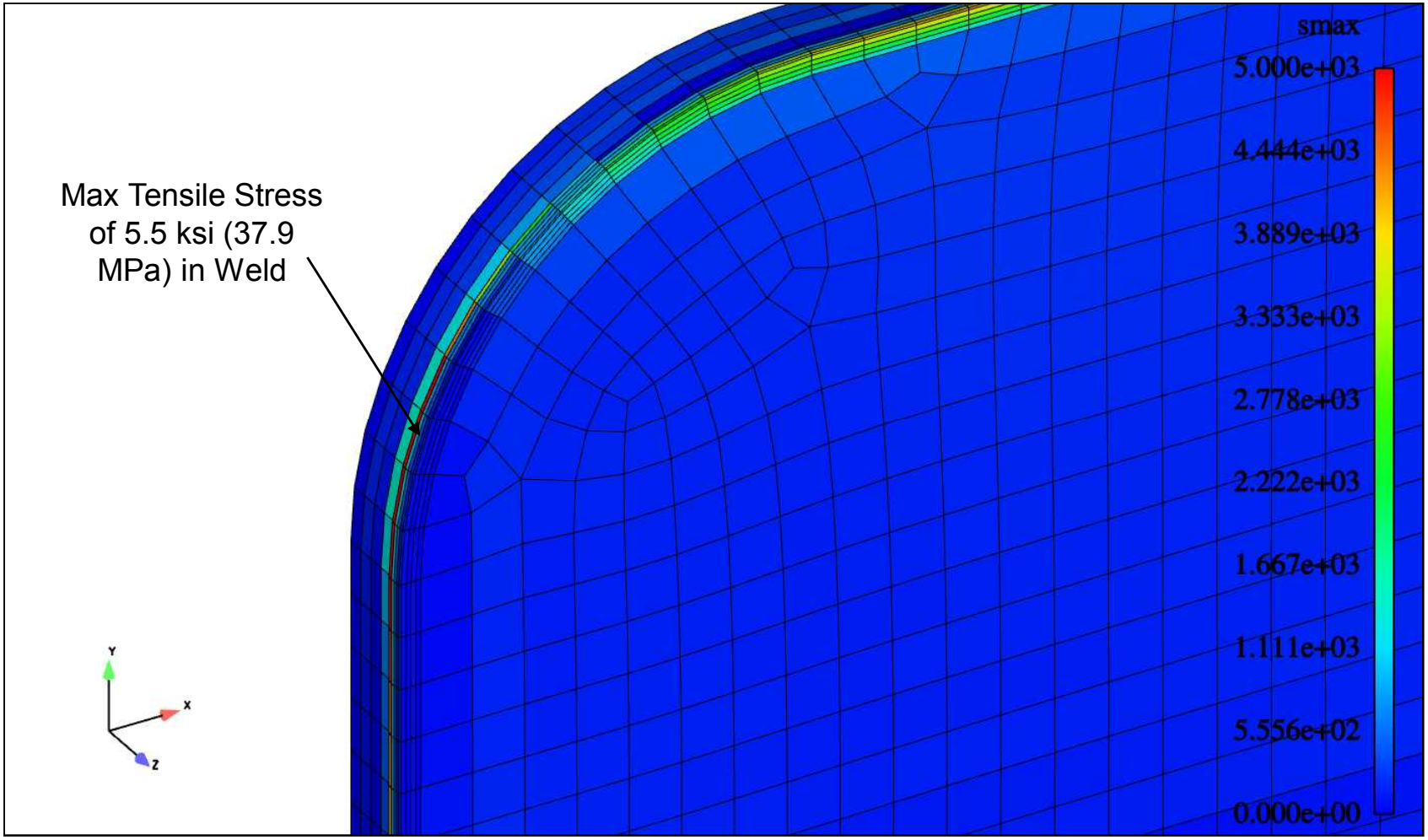
Modeling Results

- The yield stress for 4047 aluminum is ~ 28 ksi (193 MPa).
- Weld depth penetration in the model is 0.020 in (0.5 mm).
- A crack in the weld will be caused by tension on the inside edge of the weld.
- Closer inspection of the weld at the location of the max VonMises stress indicates that the peak stress is located on the outside edge of the weld. The inside edge is in compression.
- The maximum tensile stress at the inside edge occurs at the top corners of the container with a magnitude of ~ 5.5 ksi (37.9 MPa).
- Stresses are very low (even if added to encapsulation stresses).

Max Can VonMises Stress (at peak loading)

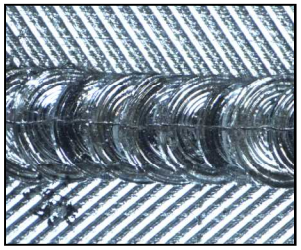


Weld Model and Results

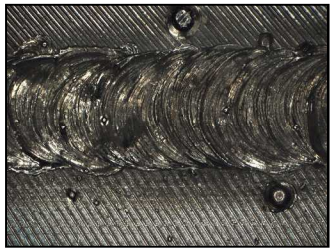


Material Selection

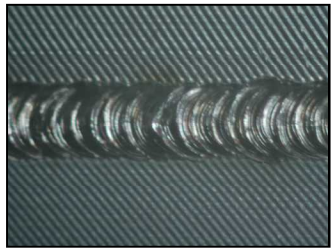
Material Selection: Al 6061/Al 4047



Al 5456/Al 6061



Al 5083/Al 6061



Al 4047/Al 6061

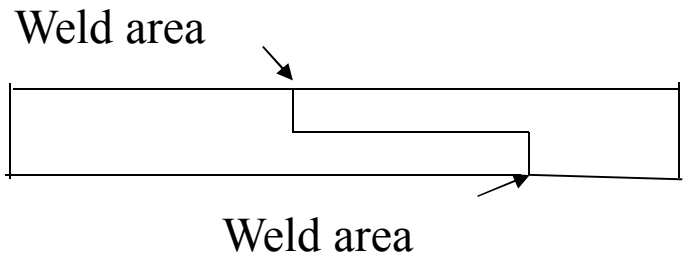
Two types of aluminum alloys were chosen as possible replacements for Al 4047. The materials were chosen for their physical properties. The 5000 series of aluminum alloys have a high Mg content and low Si content when compared to Al 4047. Vaporization of the Mg produced excessive soot and brittle welds.

Process and Material Choices

- Electron beam welding (EBW)
- Laser beam welding (LBW)
  - CW Nd:YAG
  - Pulsed Nd:YAG
  - Fiber laser
  - Disk laser
- Friction stir welding (FSW)
- Variable polarity plasma arc welding (VPPAW)

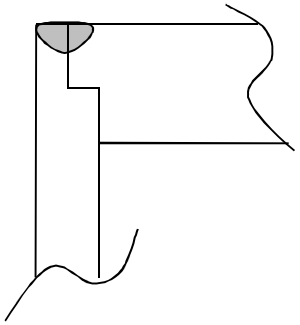
Al 4047 - Material choice for the Cover
Al 6061 - Material choice for the Container

Weld Samples



First Set of Samples:
Weld Samples were sent to 8 weld equipment manufacturers

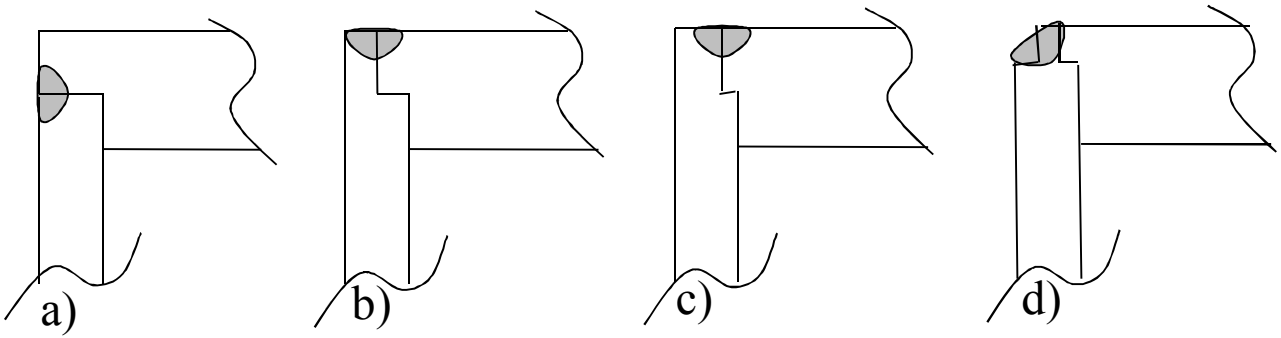
For the company tours:
Samples were closer to actual weld geometry



Second Set of Samples:
Closer to actual weld geometry

Third Set of Samples:
Samples were same shape as container

Weld Joint Configurations

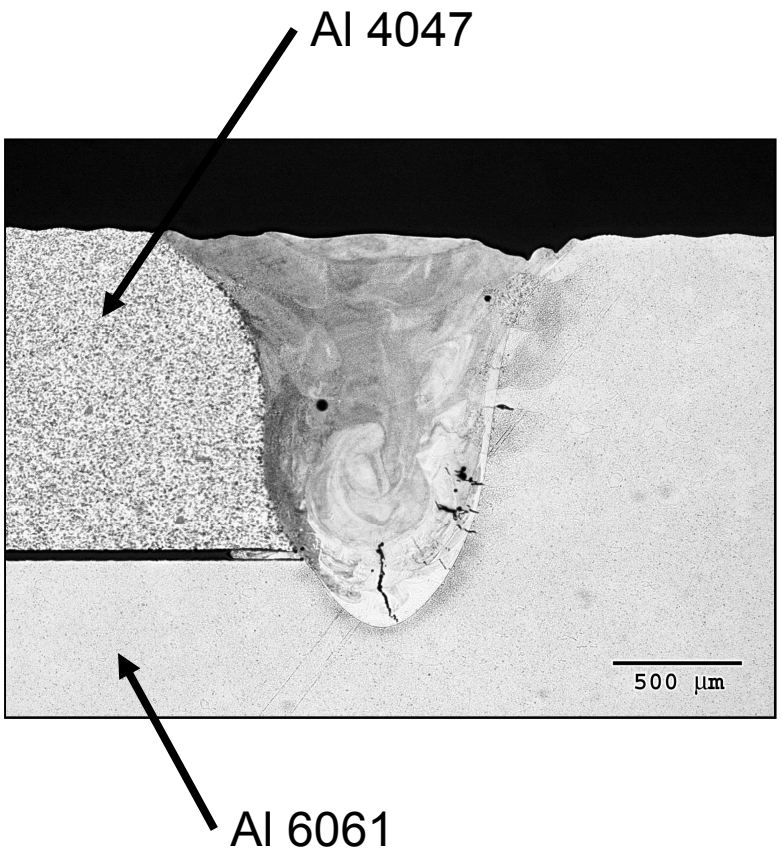


a) Side weld was the original configuration
b) Top down weld with 0.030” (0.762 mm) step on side wall of container
c) Top down weld with 0.040” (1.016 mm) step on side wall preferred by VPPAW
d) Top down weld with 0.020” (0.508 mm) consumable step

Challenges with Welding Aluminum

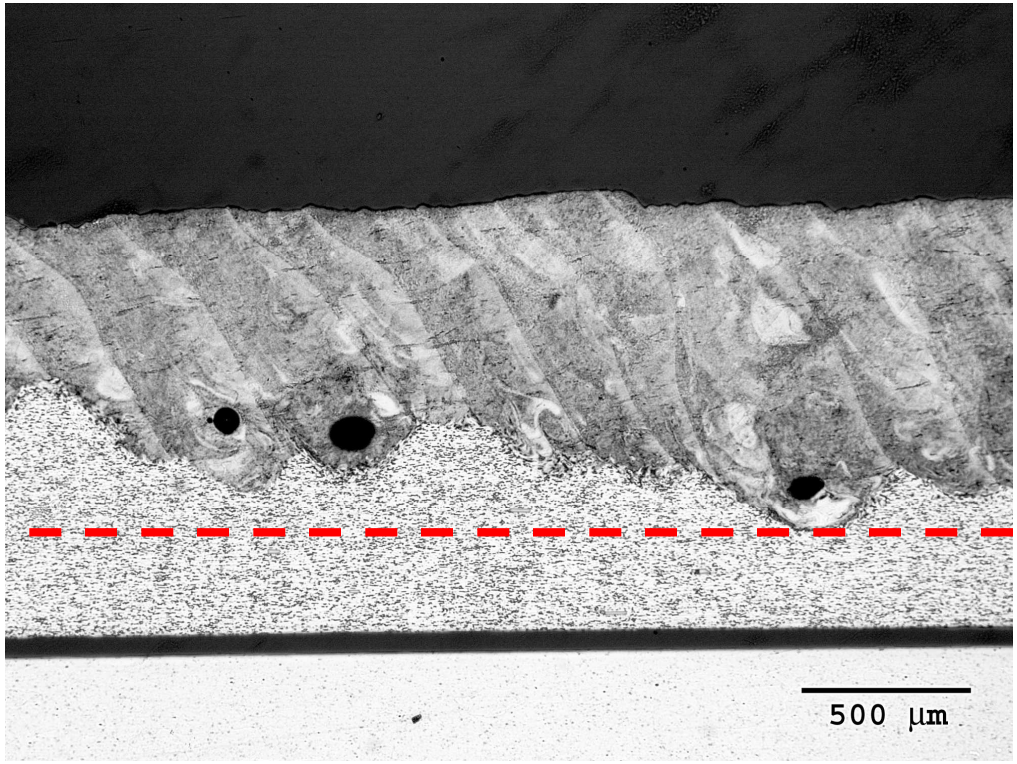
- Tenacious Oxide layer
  - There is an effort to reduce chemicals on the NG production floor
- Affinity for Hydrogen in the molten state (Porosity)
- Al 6061 is subject to liquation cracking when welded to itself
- High thermal conductivity

Weld Study



Cracking occurred in the Al 6061 where there was poor mixing.

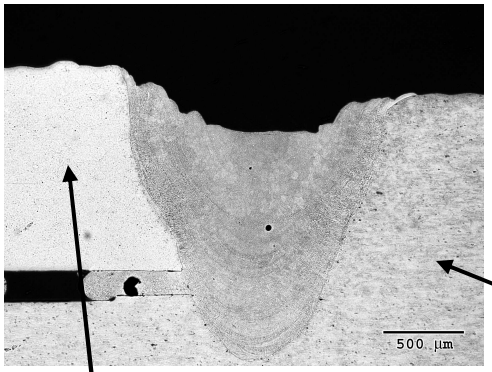
Weld Study



Inconsistent penetration can be caused by being on the edge of processing parameters for a keyhole weld.

Down Select Processes

- Electron beam welding equipment is expensive and takes a long time for chamber to pump down.
- The shape and joint configuration of the container made friction stir welding impossible without major changes to the unit
- VPPAW – the welds were large and gives off RF
- CW laser process samples had excessive heat input and poor response from the equipment manufacturer.



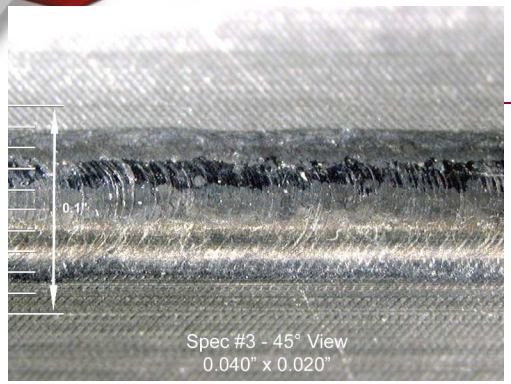
Nd:YAG CW laser weld excessive heat input

Al 4047

Al 6061

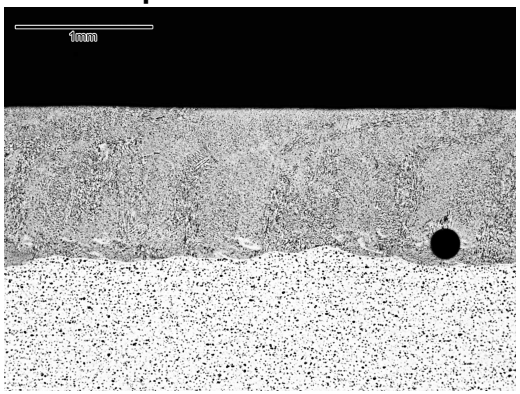
VPPAW weld large weld would need post machining

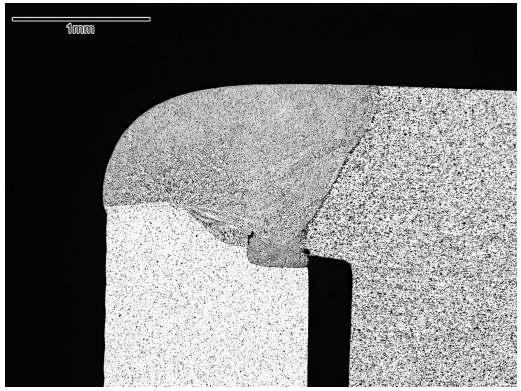
Fiber Laser



The diode pump energy is delivered to the active medium via multi-mode fibers that are connected to the multi-clad coil.

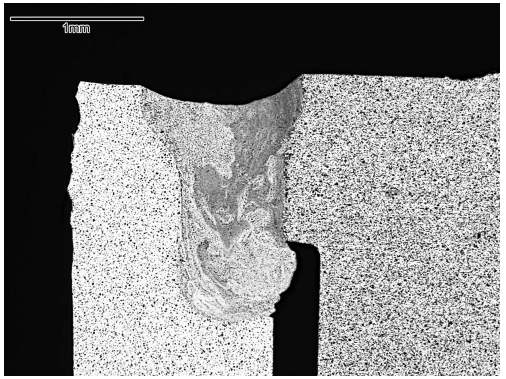
Consistent weld penetration



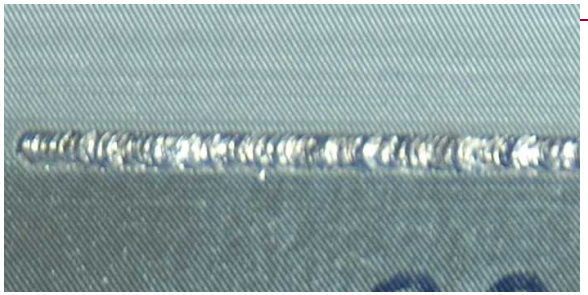


Excellent mixing between the Al 4047 and Al 6061

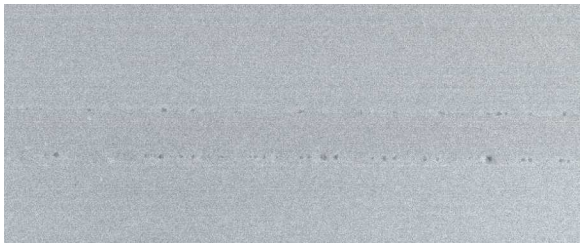
Processing parameters and joint geometry contribute to weld quality



Pulsed Nd:YAG Laser

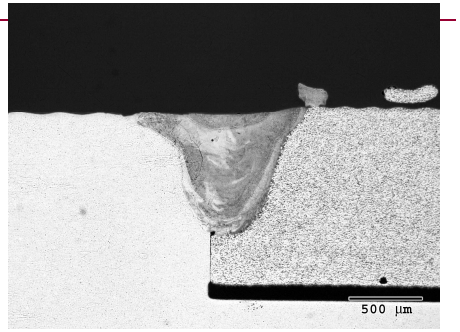


Clean weld no indication of spatter or excessive heat input.

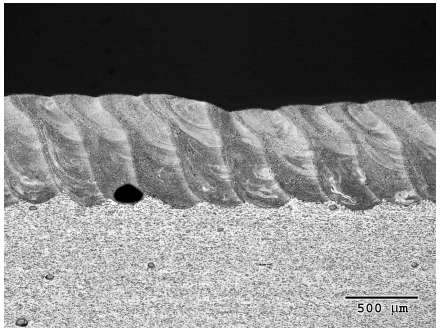


X-ray of weld reveals some small porosity pits and not cracking

Pulsed Nd:YAG laser is a solid state rod type laser. Pump light is supplied with flash lamps.

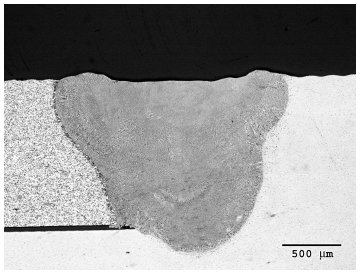


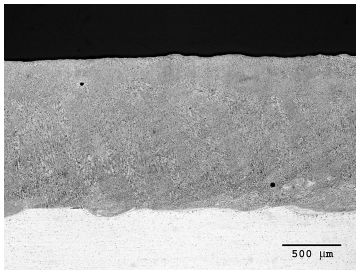
Good mixing between the Al 6061 and the Al 4047

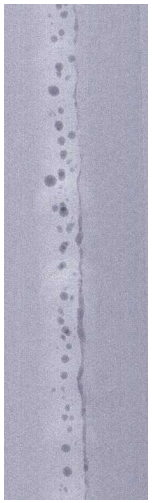


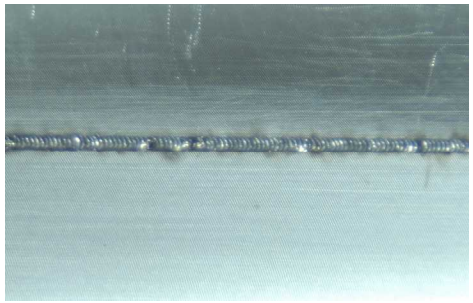
Consistent Penetration Note: Porosity Pit

Pulsed Nd:YAG Disk Laser









Capable of deep penetration weld.
Consistent weld penetration.
Porosity clearly visible in the X-ray.
Welds has some spatter and discoloration.
Probably a product of excessive heat input.

Pulsed Nd:YAG is a solid state laser that has a disk instead of a rod. Pump light is supplied with diode lasers.

KT Decision Analysis

All three laser systems are capable of welding the aluminum container to the cover.

Team – A multi-functional team consisting of design, team leads, welding experts, technologists, and production people participated in the event.

Musts – Capable of welding container to cover (laser power and travel distance), class one enclosure, specific delivery date, fit through doorway, meet exhaust requirements

Wants – Low cost, rotary motion, training, warranty, proven technology, plug efficiency, mobile, etc…..

Weigh Wants – The team decides the importance of each want by giving it a multiplier of 1 – 10.

KT Analysis Continued

System	Cost	Mobility	Age of Technology	Pulse Shaping	Plug Efficiency	Total
Rod	10	10	10	10	1	41
Disk	5	3	1	10	9	28
Fiber	4	3	5	1	10	23

The table above has some of the values for the wants. This tool is only a guide for the decision. The team discusses the outcome, makes recommendations, and decides which is the best path forward.

Future Work

- Studies will be conducted to evaluate the use of pulse shaping to reduce porosity
- Welds will also be evaluated for mixing, depth of penetration, and overall quality
- Further characterization of welds
- Fine tune motion control program