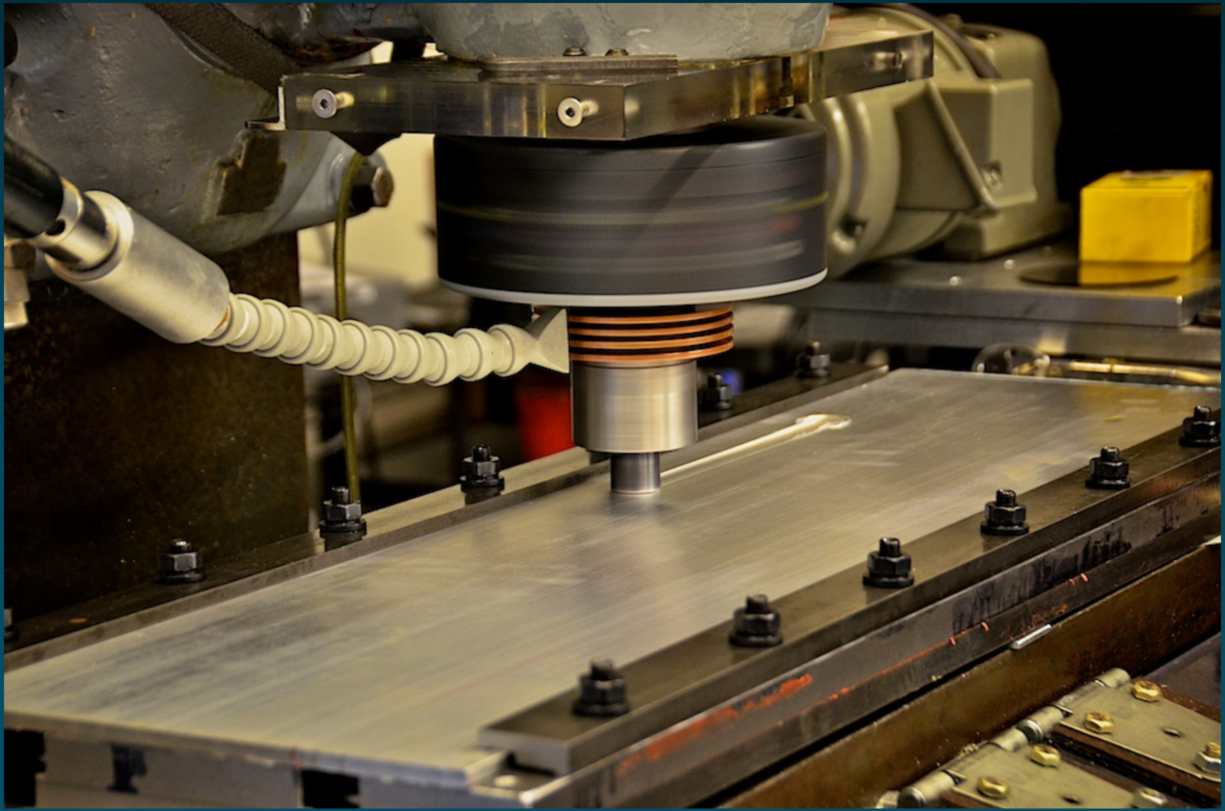
# Friction Stir Welding of Additively Manufactured Aluminum Alloys

William T. Evans, Al M. Strauss, George E. Cook, Tracie Prater

Vanderbilt University Welding Automation Laboratory (VUWAL)



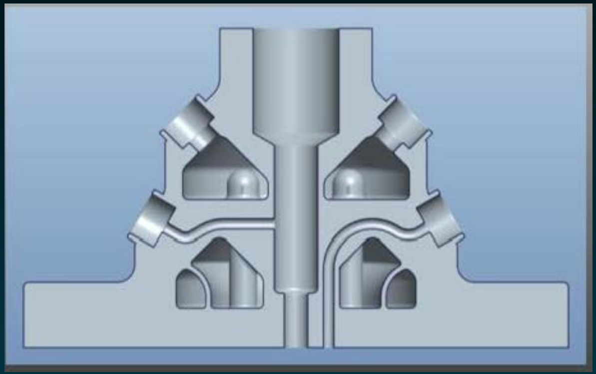
# Why Additive Manufacturing?

*RS-25 (space shuttle main engine) flex joint redesigned with selective laser melting. Part count reduced from 45 to 17 and number of welds reduced from 70 to 26 Image credit: NASA.*

- **Produce near net-shape monolithic parts that reduce the part count and number of welds in an assembly**
- **Enable rapid iteration of the design/build/test loop to accelerate new hardware development**
- **Impart significant cost and time savings for certain hardware applications**
- **Flexibility in design and delivery of feedstocks (ex. custom blends and functionally gradient materials)**

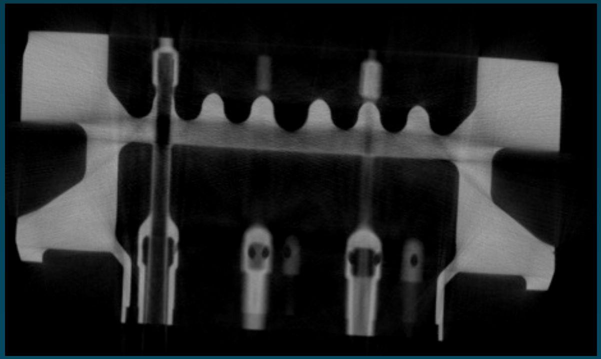
# Primary Challenges in AM

Materials Characterization



Standard Design Practices

Process Modeling, Monitoring, & Control



Certification

# Additional Challenge for AM: Welding

- Limited part size due to size of the build chamber/platform for AM
- There is little published data related to welding of additively manufactured material in the open literature
- Weldability will be impacted by a number of variables which influence material outcomes
  - Machine and Manufacturing Process used- ie processing parameters
  - Feedstock characteristics
  - Material postprocessing

<u>Welding of AM parts is an eventuality.</u>
Therefore, there is a clear need for studies of the weldability of additively manufactured components to themselves or to conventionally manufactured components in assemblies

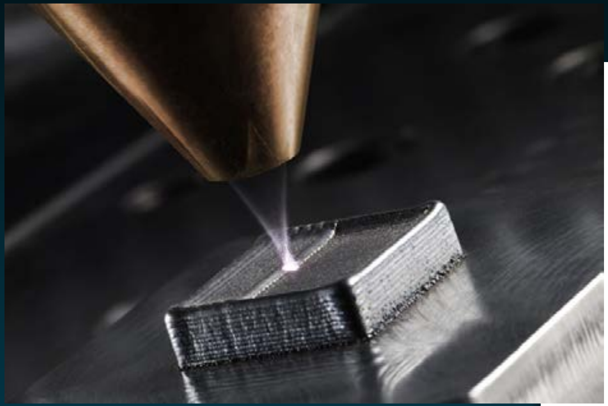
# Scope and Objective of Study

Investigate the Friction Stir Welding of additively manufactured Aluminum and assess how the joint properties for these materials compare with welds of conventionally manufactured material

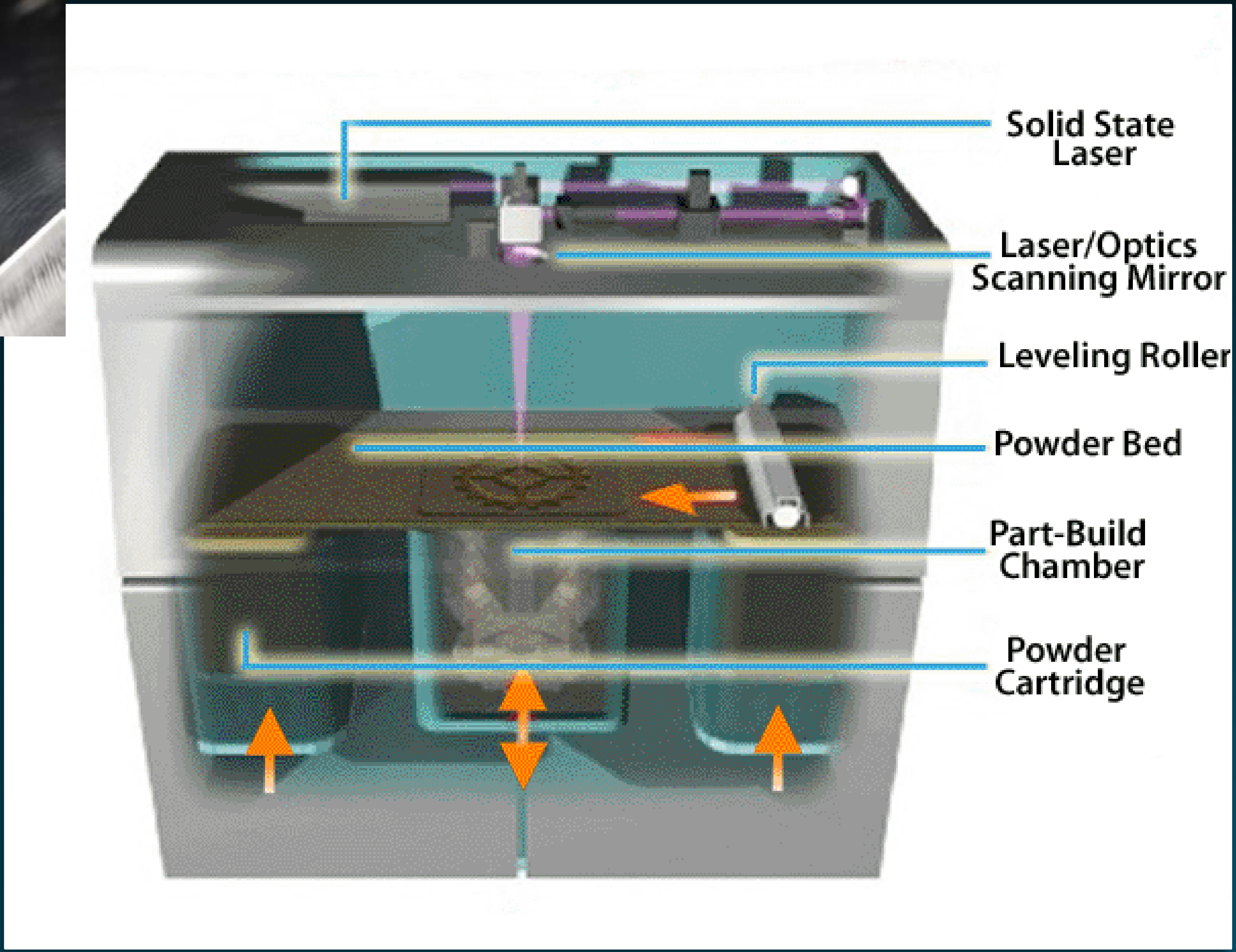
- -Compare welds of AM material with parent AM material
- -Compare welds of AM material with conventional material
- -Initial study of 3 materials produced using 3 different AM techniques

| Material | Process | Process type |
|---|---|---|
| Al 2219 | Electron Beam Freeform Fabrication | Directed energy deposition (metal wire) |
| AlSi10Mg | Direct Metal Laser Sintering | Powder bed fusion |
| Al 6061 | Ultrasonic additive manufacturing | Sheet lamination |

# Process Overview: Direct Metal Laser Sintering



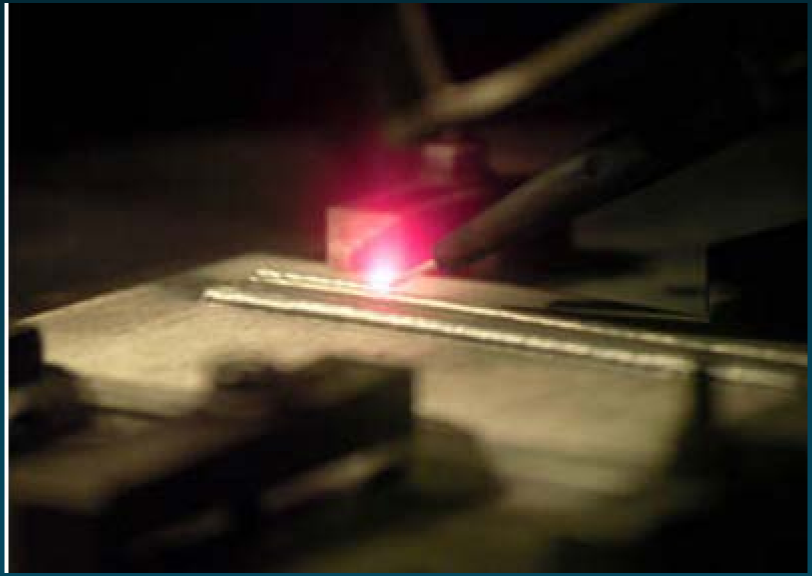
- Thin layer of metal powder is fed onto the build plate
- Laser selectively sinters deposited powder
- Build table is lowered and additional powder is fed onto plate
- Process is repeated layer by layer until part is complete




<u>Process used in this study to produce AlSi10Mg plates</u>

# Process Overview: Electron Beam Freeform Fabrication

- Process originally developed by NASA Langley Research Center
- Uses an electron beam and solid wire feedstock to print metal structures
- Requires a vacuum to operate



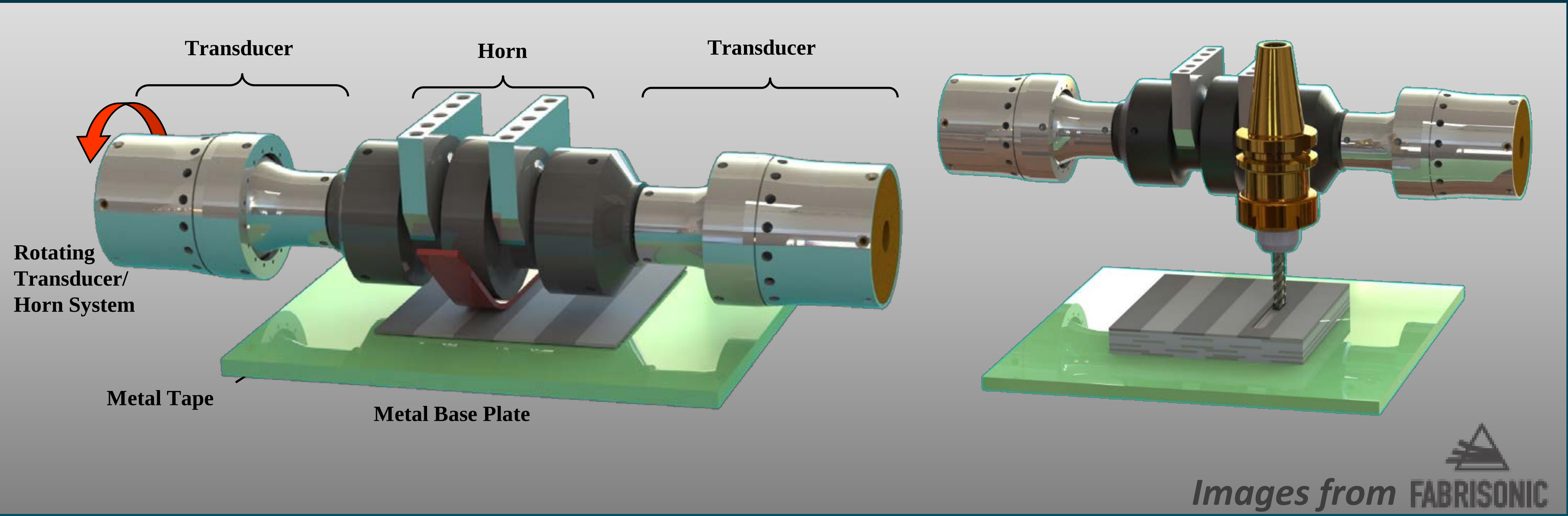
EBF3 process
Image credit: NASA

Structural part produced with EBF3
Image credit: NASA

<u>Process used in this study to produce Al 2219</u>

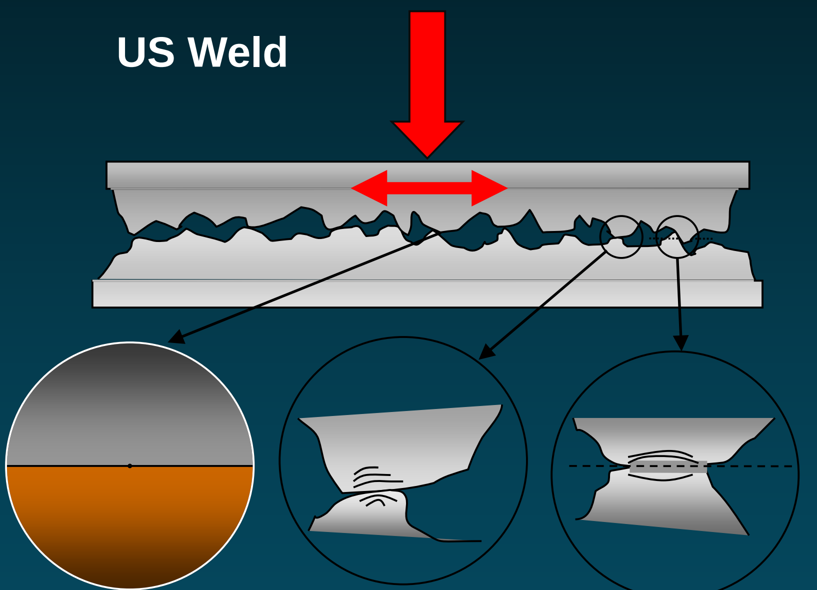
# Process Overview: Ultrasonic Additive Manufacturing

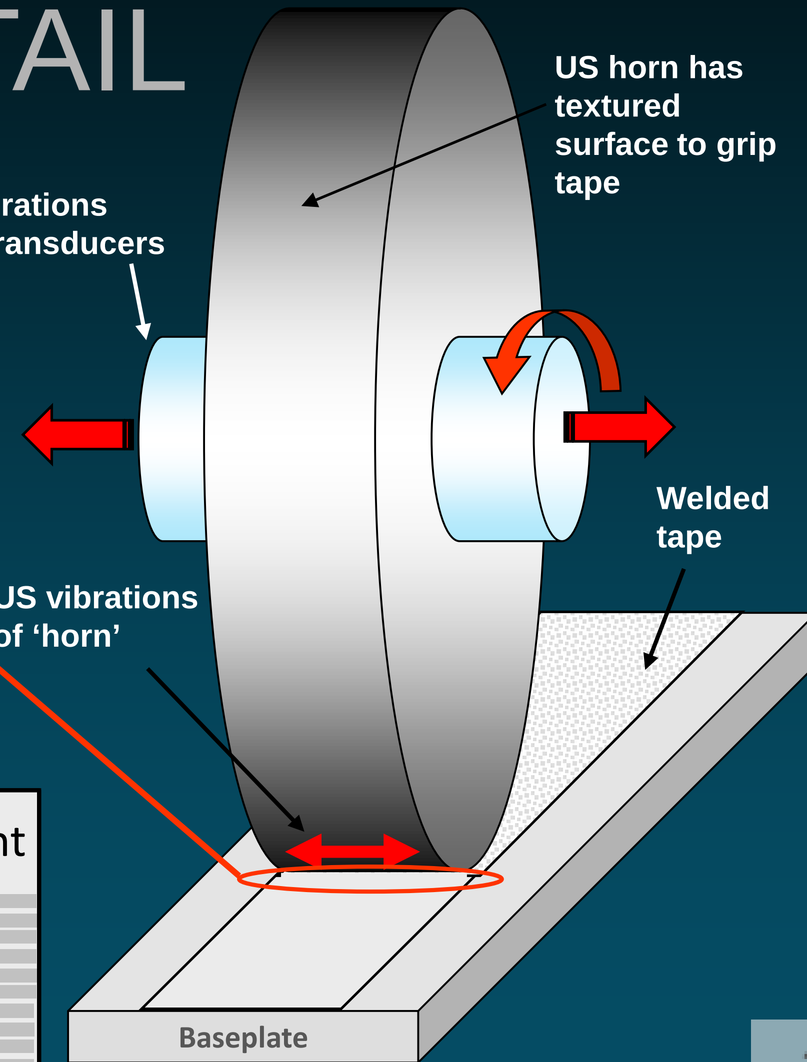
… a new technology – "UAM" creates net-shape solid metal parts using solid state ultrasonic metal welding and CNC contour milling

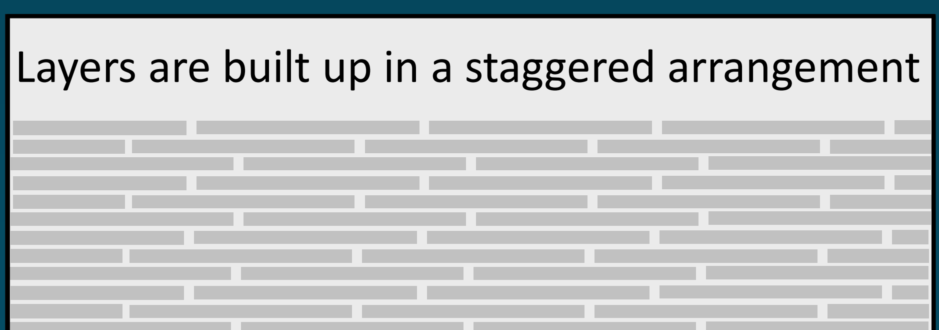


# Process Overview: Ultrasonic Additive Manufacturing

## A BIT MORE DETAIL

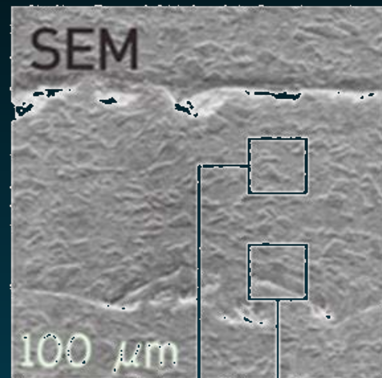


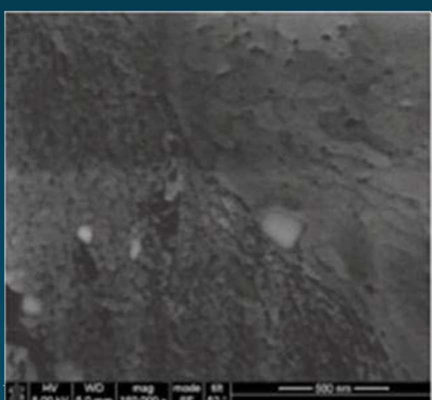




FABRISONIC

# Materials




## Metallurgy

- Peak temperatures <0.5T melt
- Solid state process that preserves parent material structure
- Recrystallization at interface
- Local formation of nano-grain colonies
- Can bond dissimilar metals and embed electronics

FABRISONIC

Process used in this study to produce Al 6061 plates

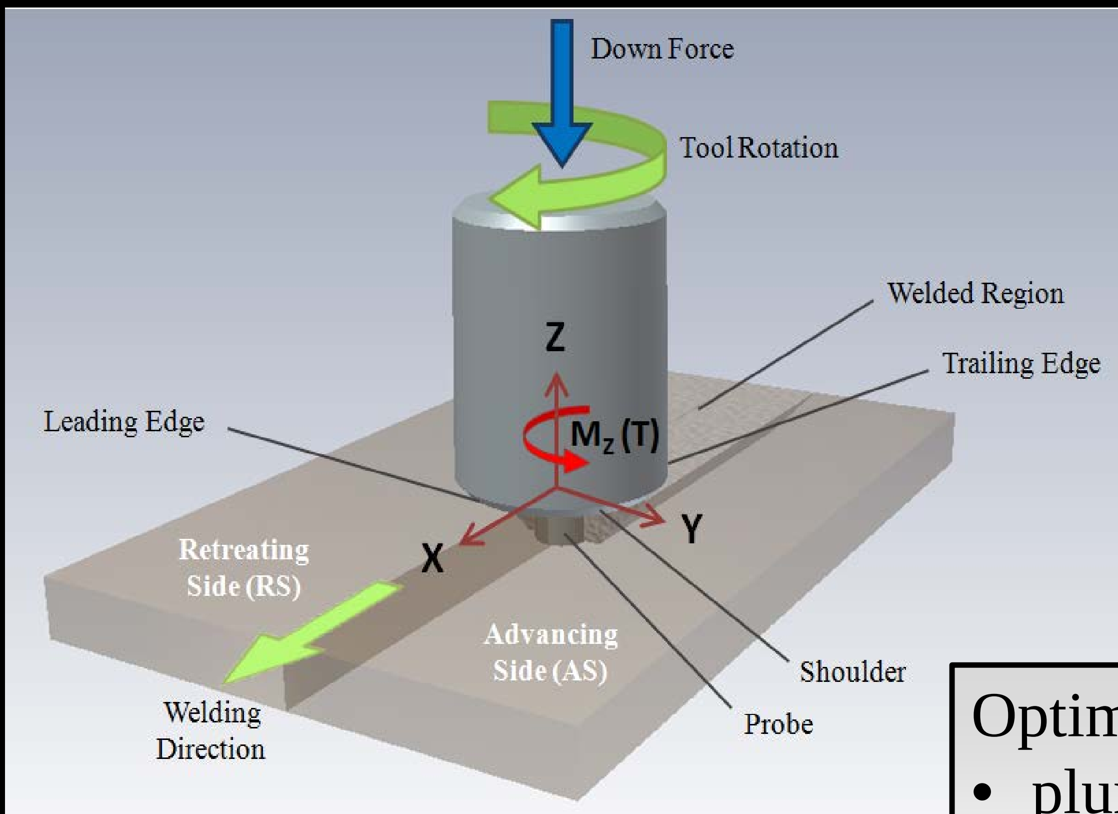
# Materials

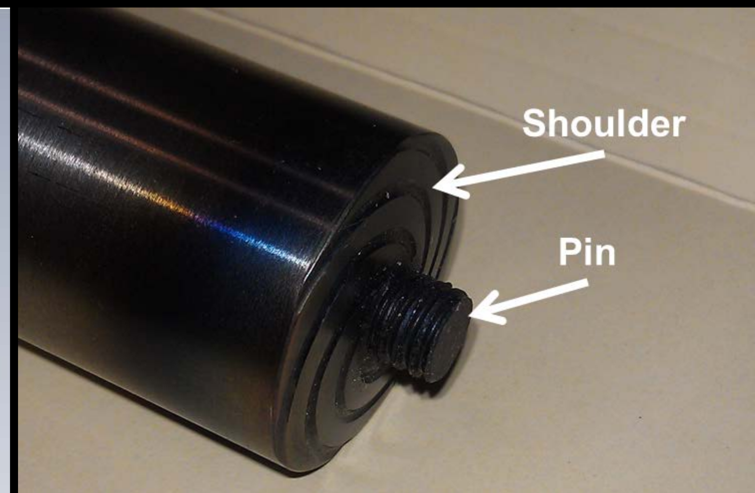
Ultrasonic Additively Manufactured 6061

Electron Beam Free Form Fabrication 2219

Direct Metal Laser Sintered AlSi10Mg

# Friction Stir Welding: Process and Tool Design

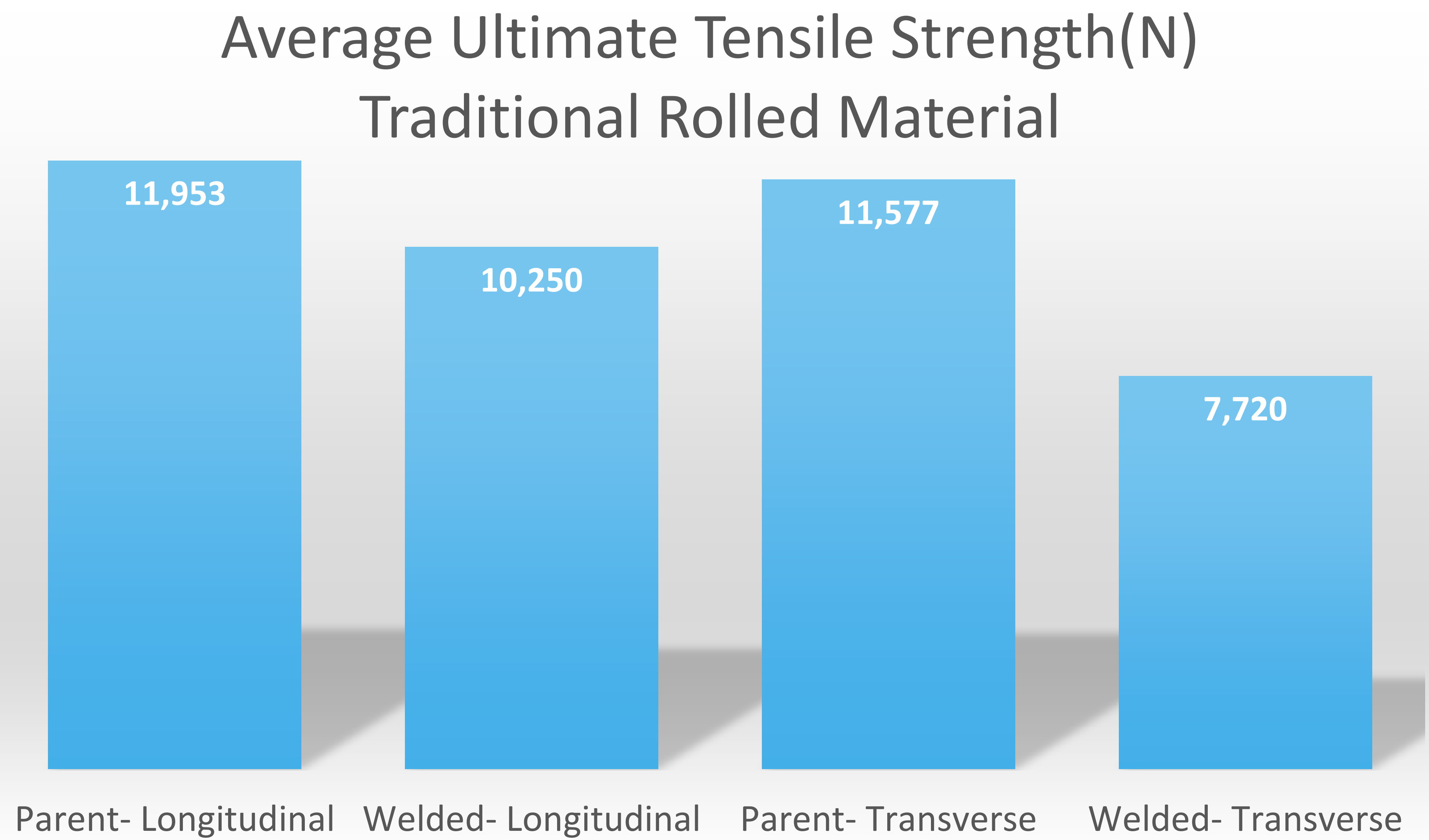



Optimized process parameters:

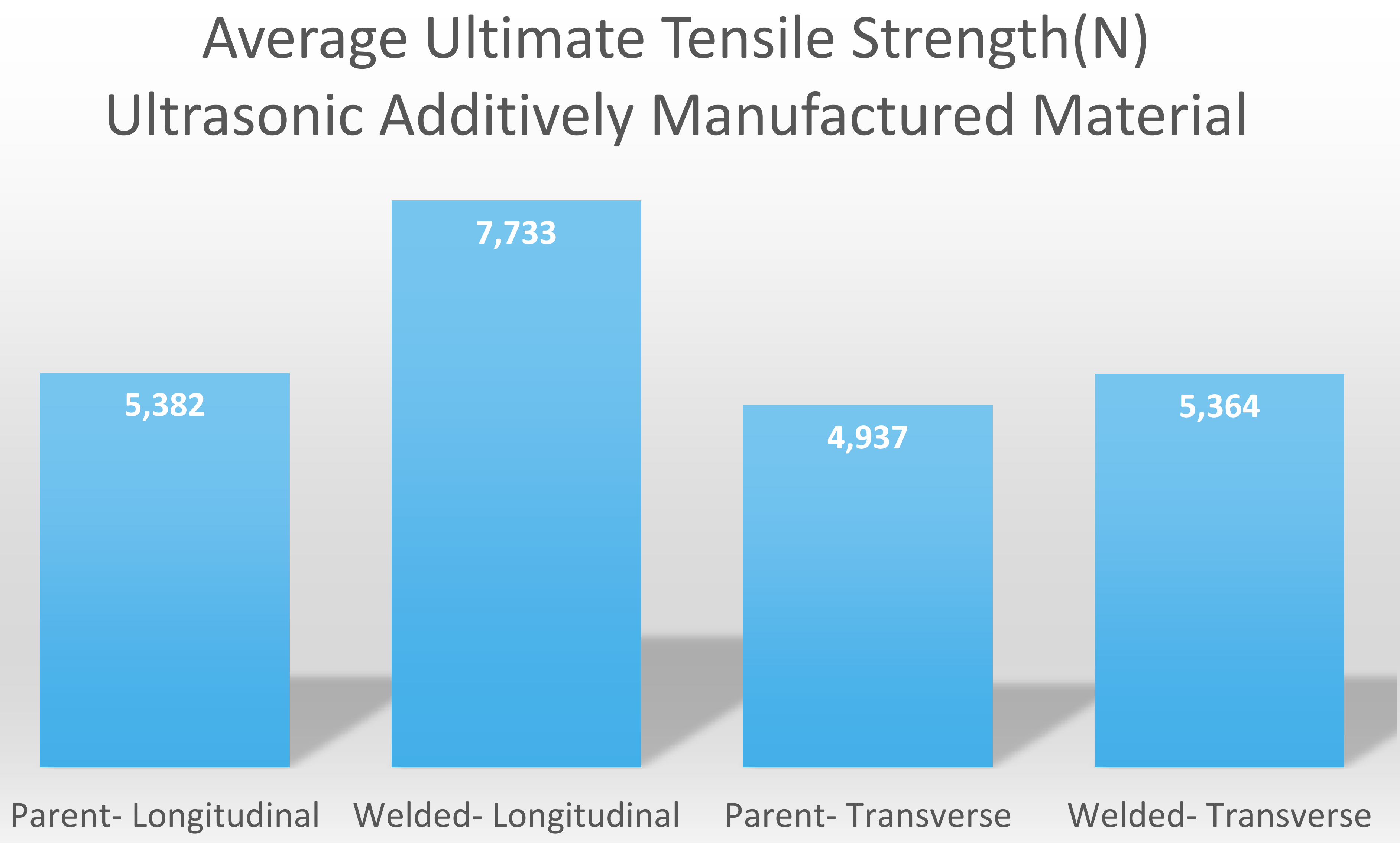
- plunge depth- 0.2 in.
- traverse speed- 6 ipm
- rotation speed- 1400 RPM

# Friction Stir Welding: Ultimate Tensile Strengths for Al 6061 T6

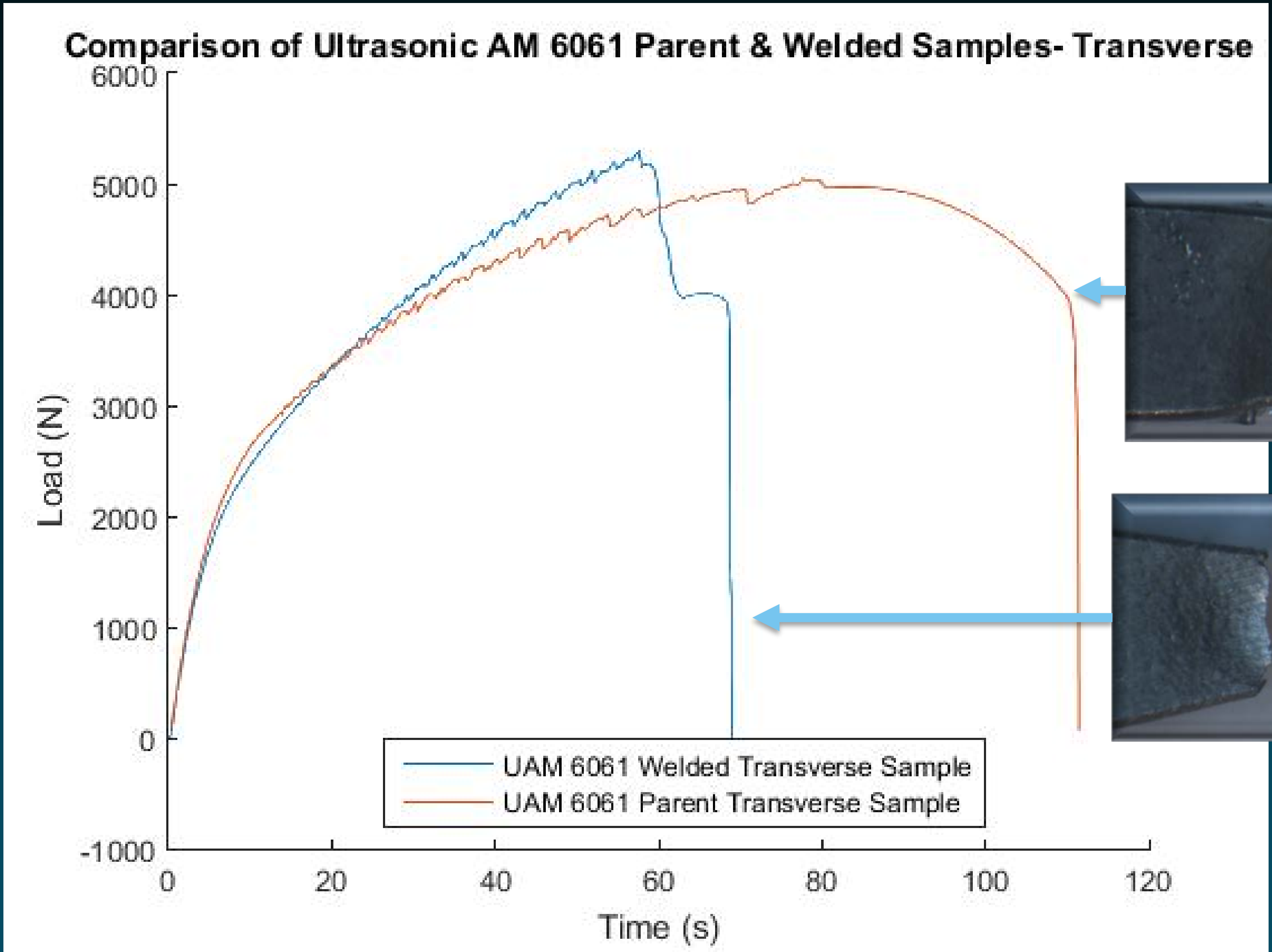



**Rolled AM 6061 is not an appropriate analog for material manufactured with UAM (foil for UAM is in H18 condition)**

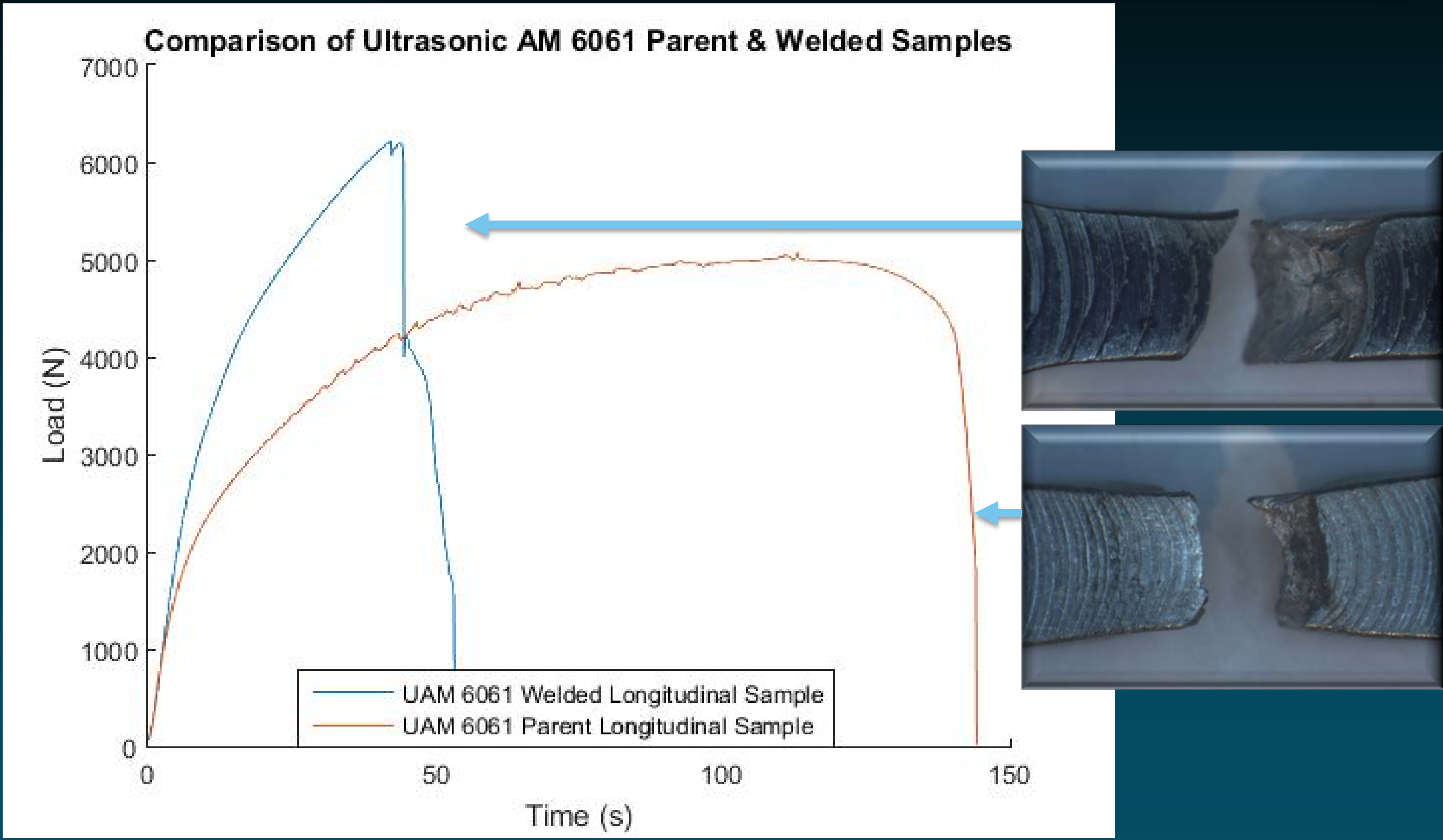
# Friction Stir Welding: Ultimate Tensile Strengths for UAM



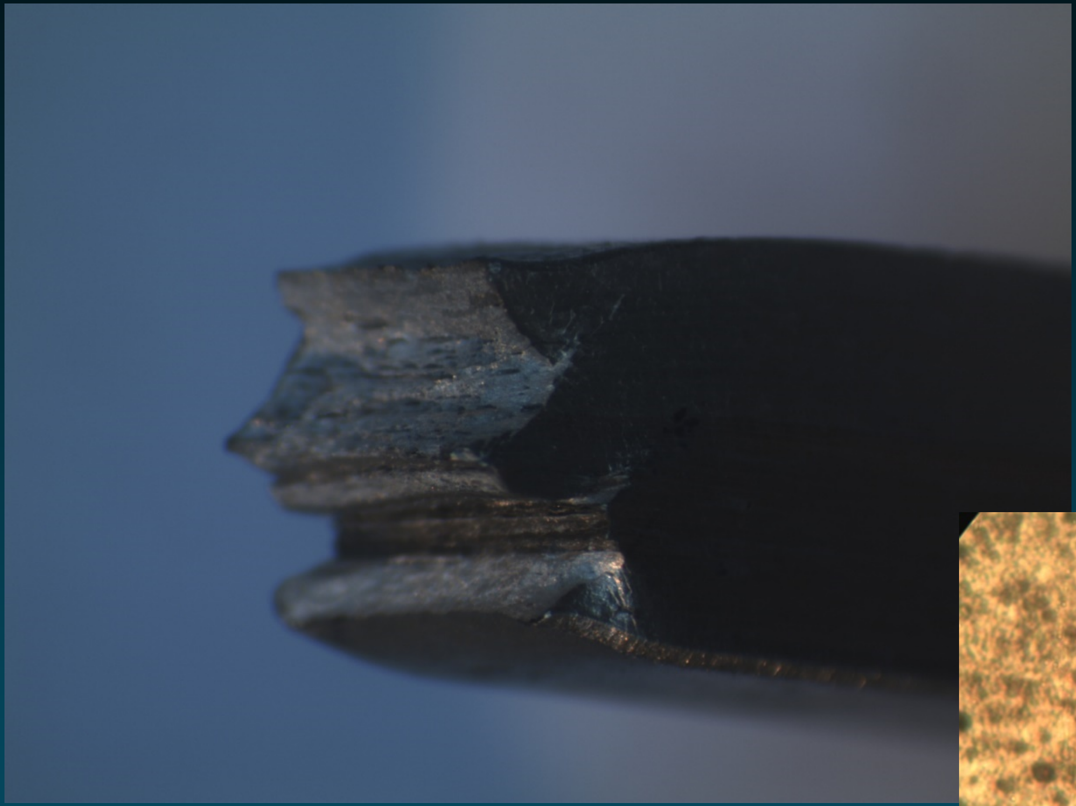
# Tensile Results- Transverse Samples

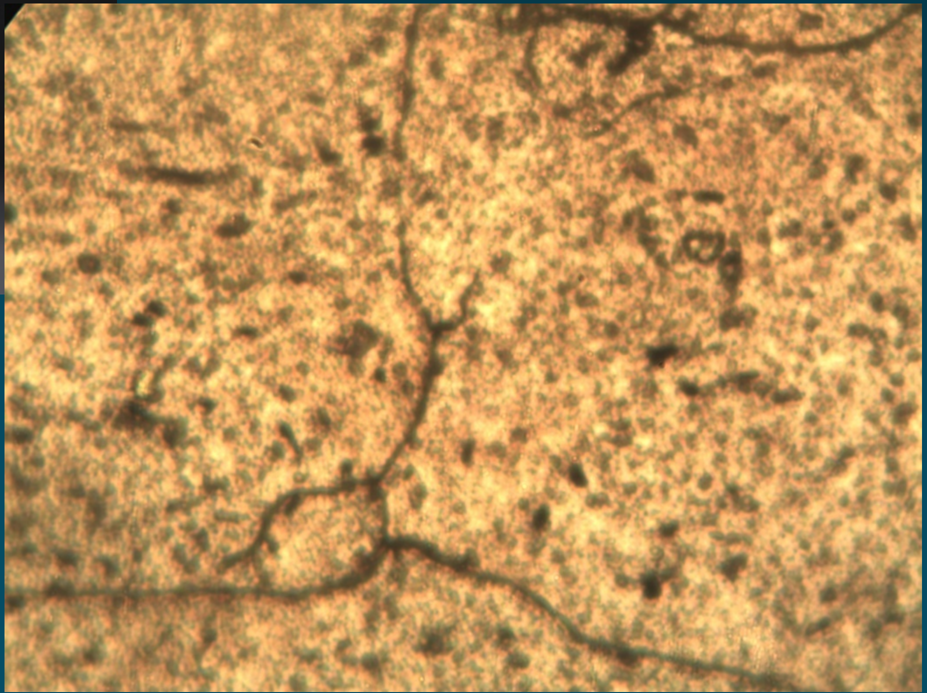



# Tensile Results- Longitudinal Samples

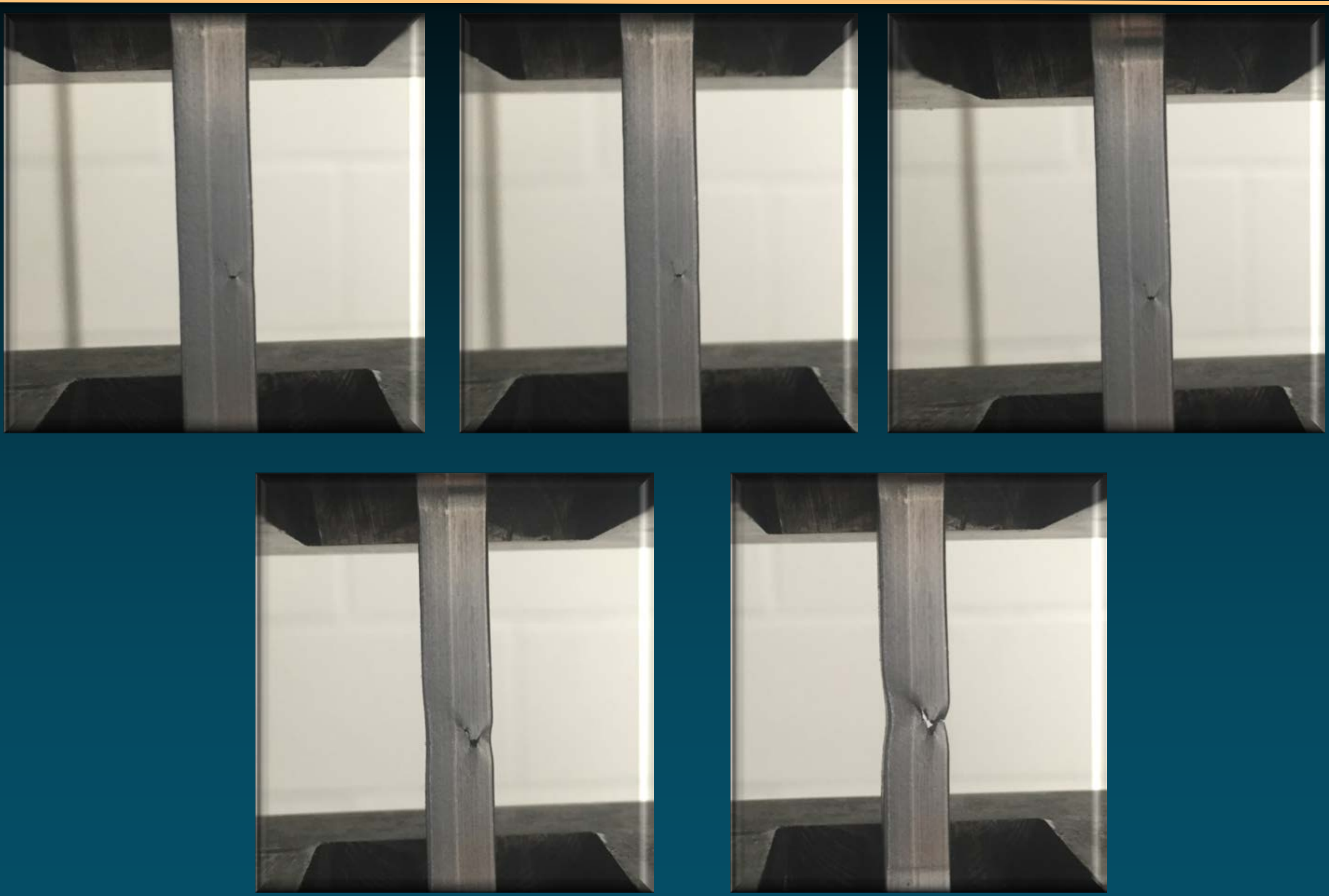


# Tensile Results- UAM Layers

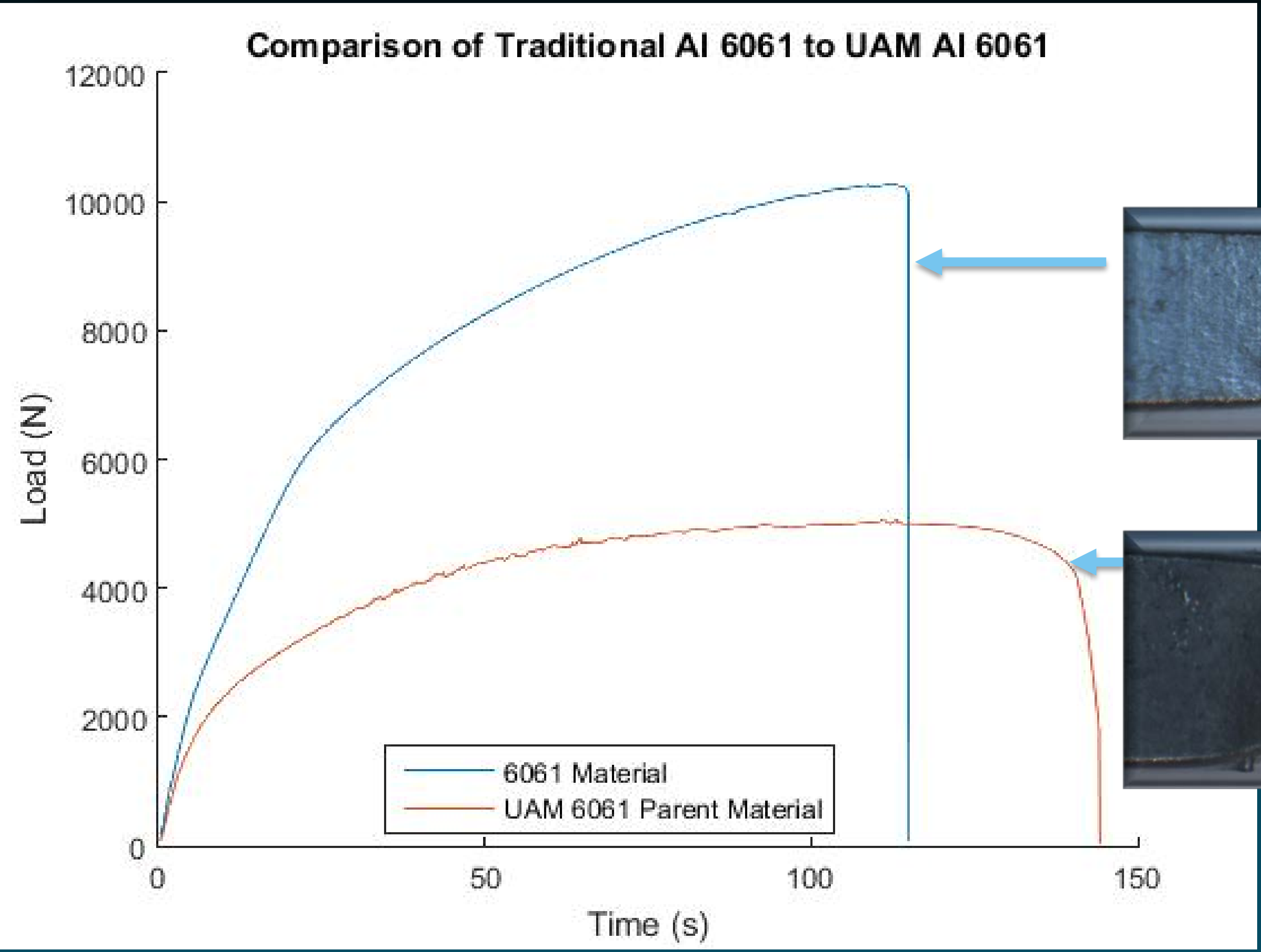




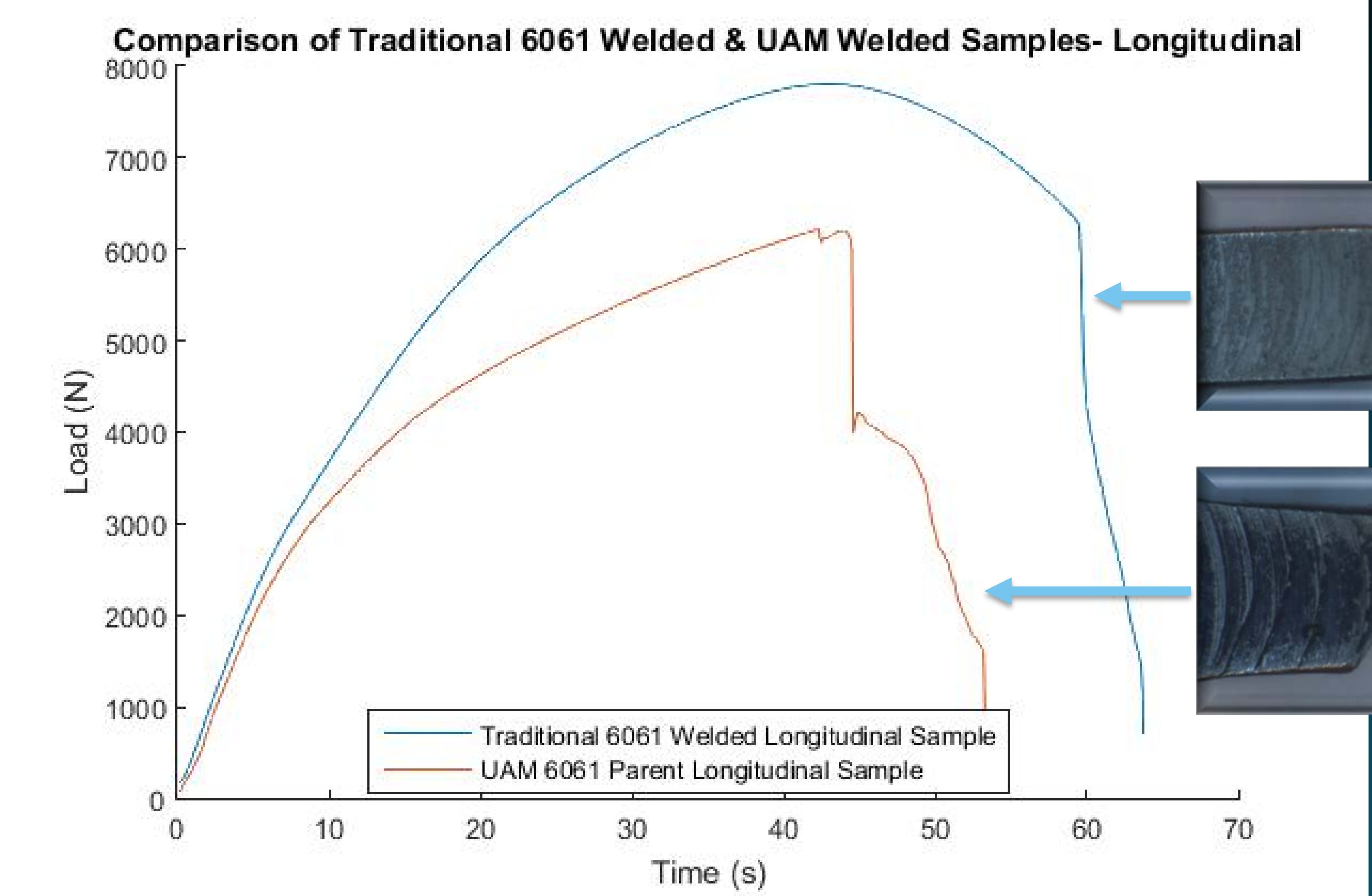
# Tensile Results- Crack Initiation



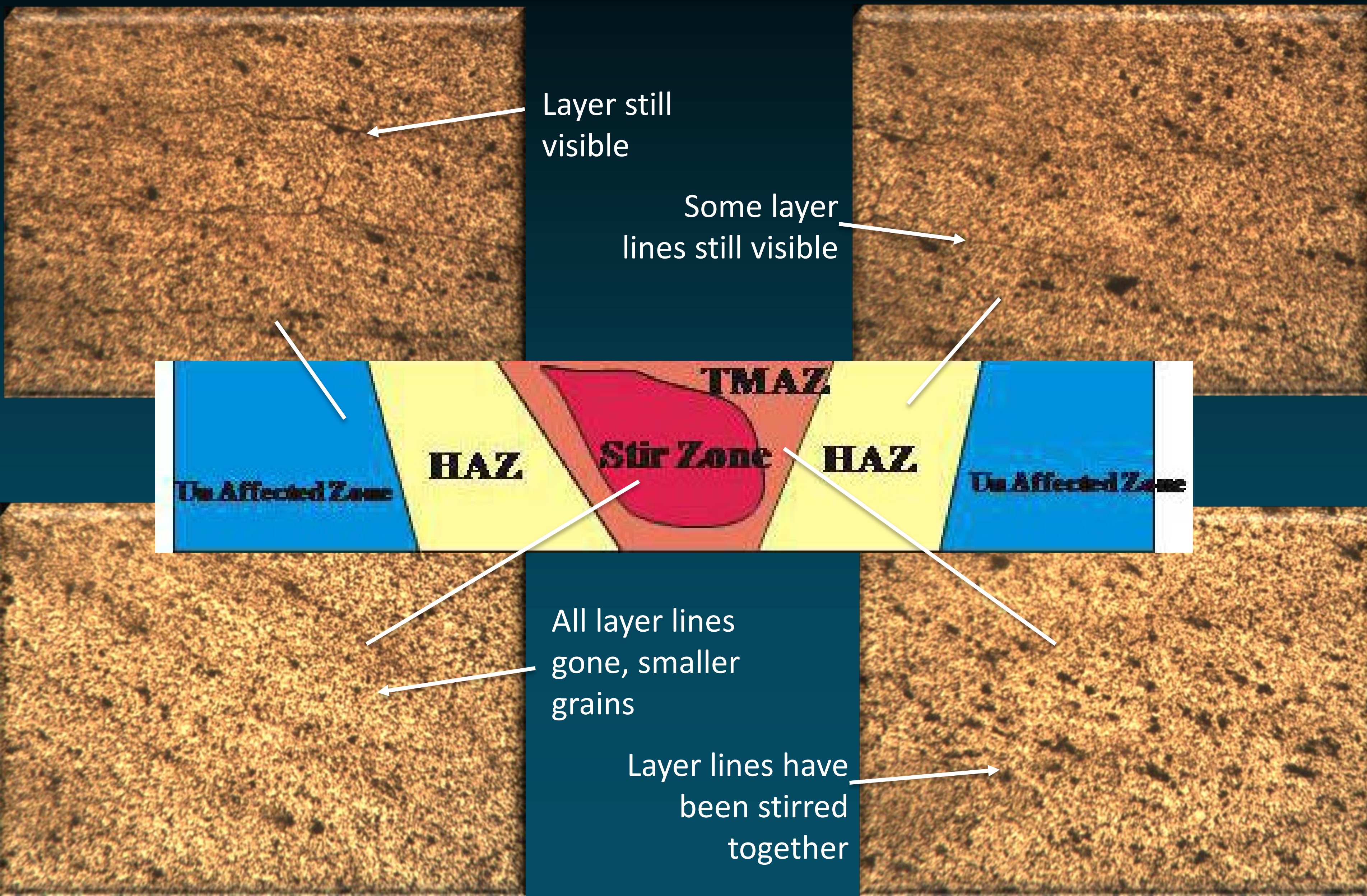
# Tensile Results




# Tensile Results




# Friction Stir Welding: Ultrasonic Additively Manufactured Material



# Conclusions

- Friction Stir Welding is an effective welding solution for Ultrasonic Additively Manufactured 6061

- Despite the inherent differences in base materials and heat treatments, tensile tests of longitudinal samples of UAM and conventionally manufactured Al 6061 T6 had very similar characteristics.

- Friction Stir Welding significantly enhances  the material properties by stirring the layers, creating diffusion bonding, and reducing the grain size

# Next Steps

- FSW UAM 6061 material to traditional 6061
- Optimize FSW process for EBF3 2219 material and determine the effects of post and pre weld heat treatment
- Optimize FSW process for DMLS AlSi10Mg and test
- Future potential research directions
  -evaluate the effect of material build orientation on joint properties
  -study welding of same alloy produced using different additive manufacturing techniques

# Acknowledgements

Special thanks to:

Tracie Prater- NASA
Mark Norfolk- Fabrisonic
Karen Taminger- Langley Research Center, NASA

Funding provided by the NASA Space Grant Consortium