Effects of notch location and orientation in WAAM qualification

CCWJ CANADIAN CENTRE FOR WELDING + JOINING

UNIVERSITY OF ALBERTA

Mia Abdulla, J. Eduardo Alvarez Rocha, Prof Felipe Castro Cerda, and Prof. Patricio F. Mendez

Background & Objectives

- Notch location and orientation remains vague in AM component qualification.
- This study investigates whether the current ASME Section IX sampling requirements adequately capture the influence of location and orientation on the mechanical properties of AM components.

Methods

- Using the Lincoln Electric RND WAAM Machine a thick wall was printed using ER70S-6 wire. The wall was then sectioned and macroetched to find individual notch locations and orientations.

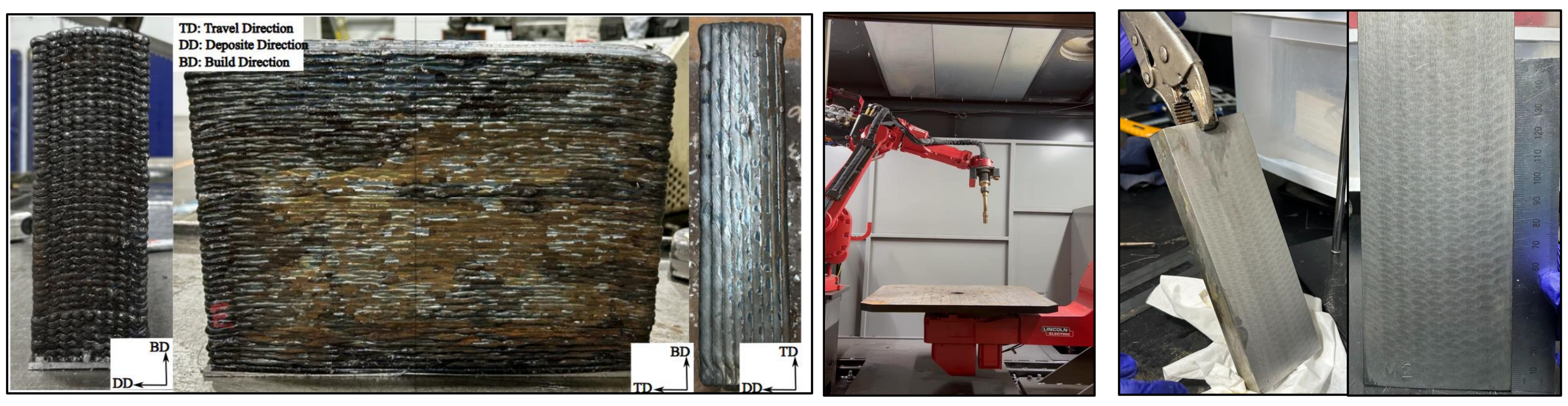


Figure 1: Thick Wall printed using the Lincoln electric WAAM Machine and macroetched surfaces.

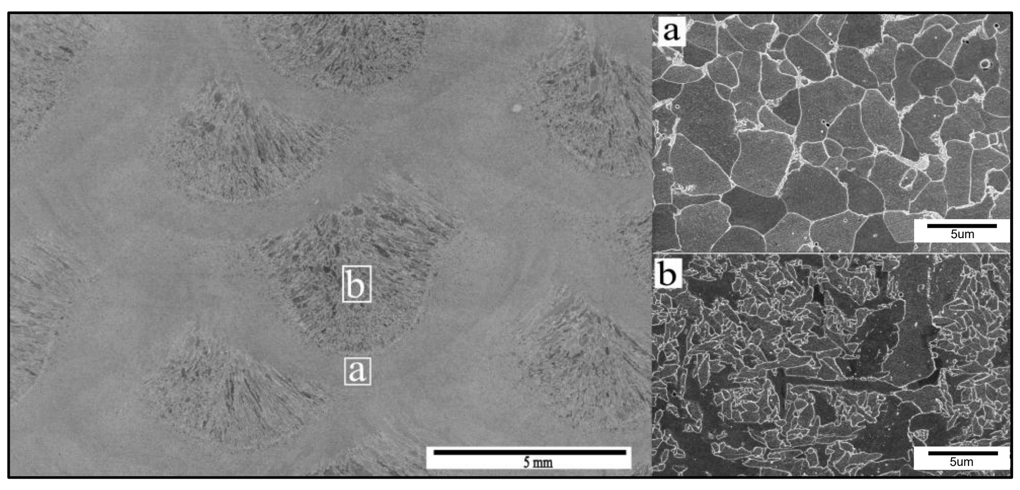


Figure 2: SEM micrographs of the two primary microstructural regions: bead and reheated zone.

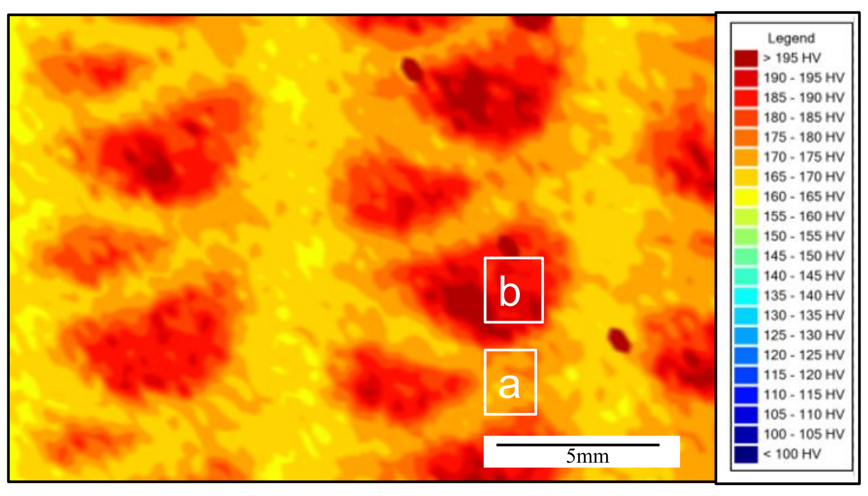


Figure 3: Hardness map used to identify the bead and reheated regions.

Table 1: Average Process parameters

Parameter	Value
Voltage (V)	24
Current (A)	243
Travel Speed (mm/s)	6.2
Bead Overlap%	35
Beads per layer	9

- Three regions of interest were identified: the bead center, reheated zone (RHZ) between adjacent beads, and RHZ between subsequent layers.
- SEM and hardness mapping distinguished the bead and RHZ microstructures, with a hardness difference of approximately 40 HV.
- Mechanical test coupons will be positioned within individual microstructural regions, enabling their properties to be evaluated independently.

Notch location + orientation

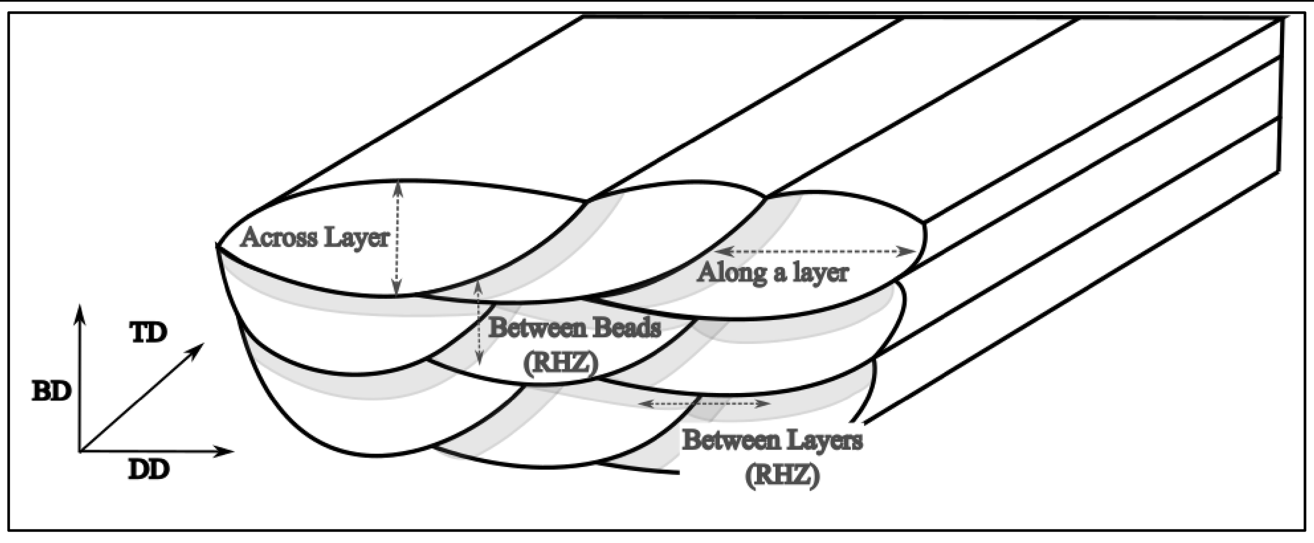


Figure 4: Notation for CVN notch location and crack propagation direction.

Set ID	Notch location	Crack propagation direction
Red 1	Along a layer	TD
Red 2	Between layers	TD
Green 1	Across layers	TD
Green 2	Between beads	TD
Orange 1	Across layers (initiating at bead)	DD
Orange 2	Across layers (initiating at RHZ)	DD
Blue 1	Across a bead (initiating at bead)	BD
Blue 2	Across a bead (initiating at RHZ)	BD

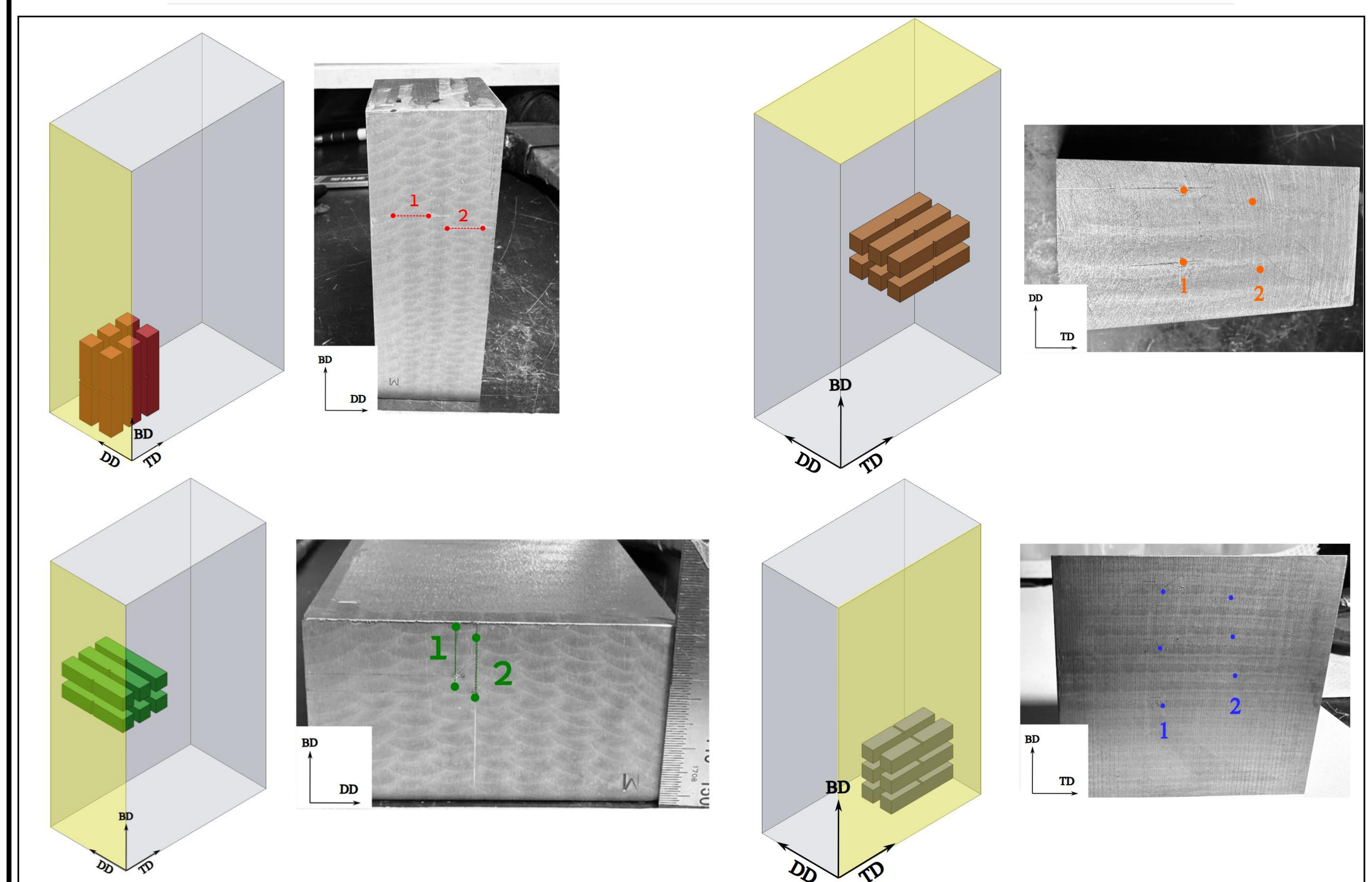


Figure 5: Notch location and orientation on macro-etched surfaces

Instrumented impact results

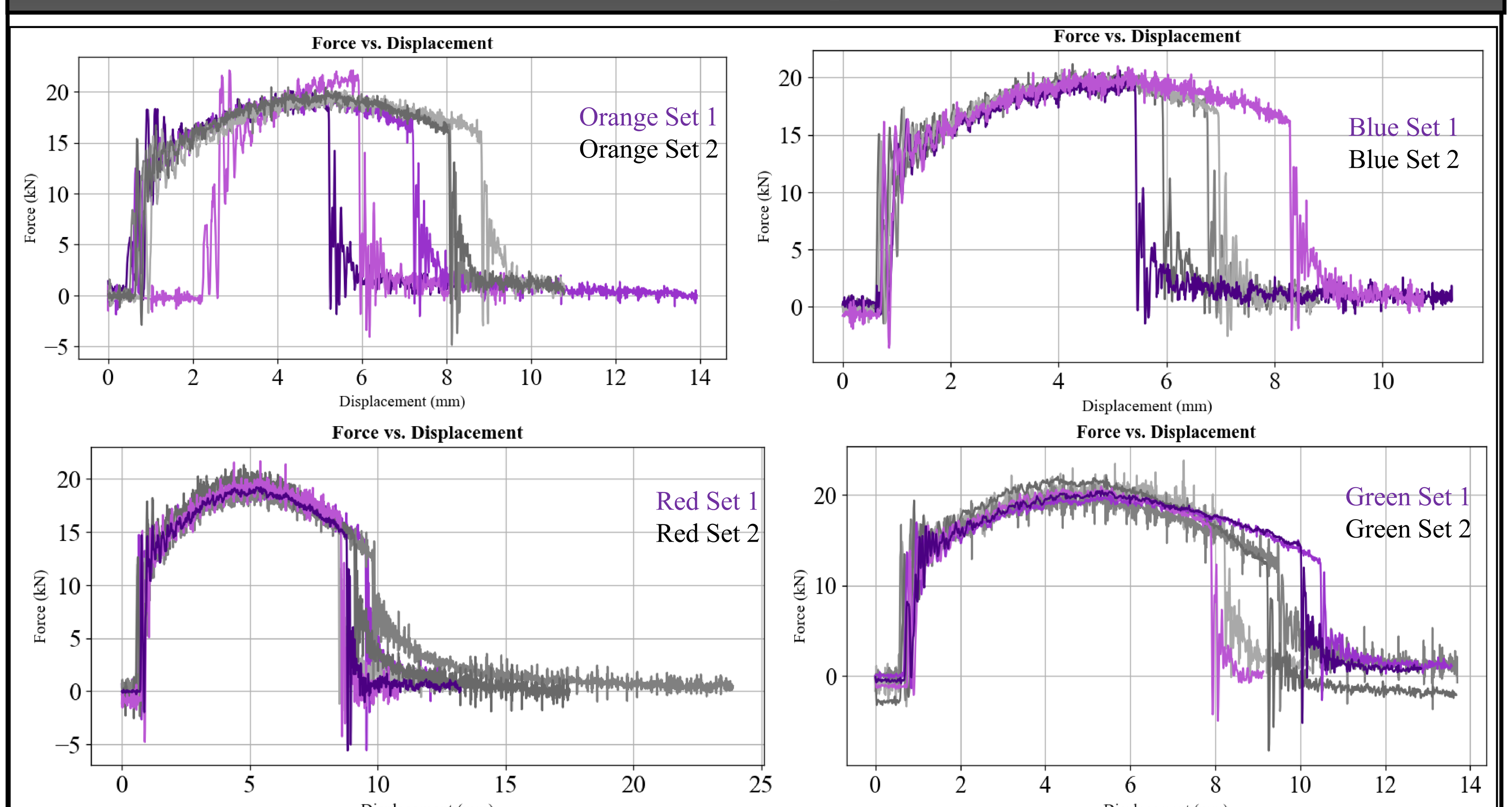


Figure 6: Instrumented force vs. displacement curves for all CVN specimens. Each plot represents one specimen orientation, with three specimens shown for each notch location (Sets 1 and 2).

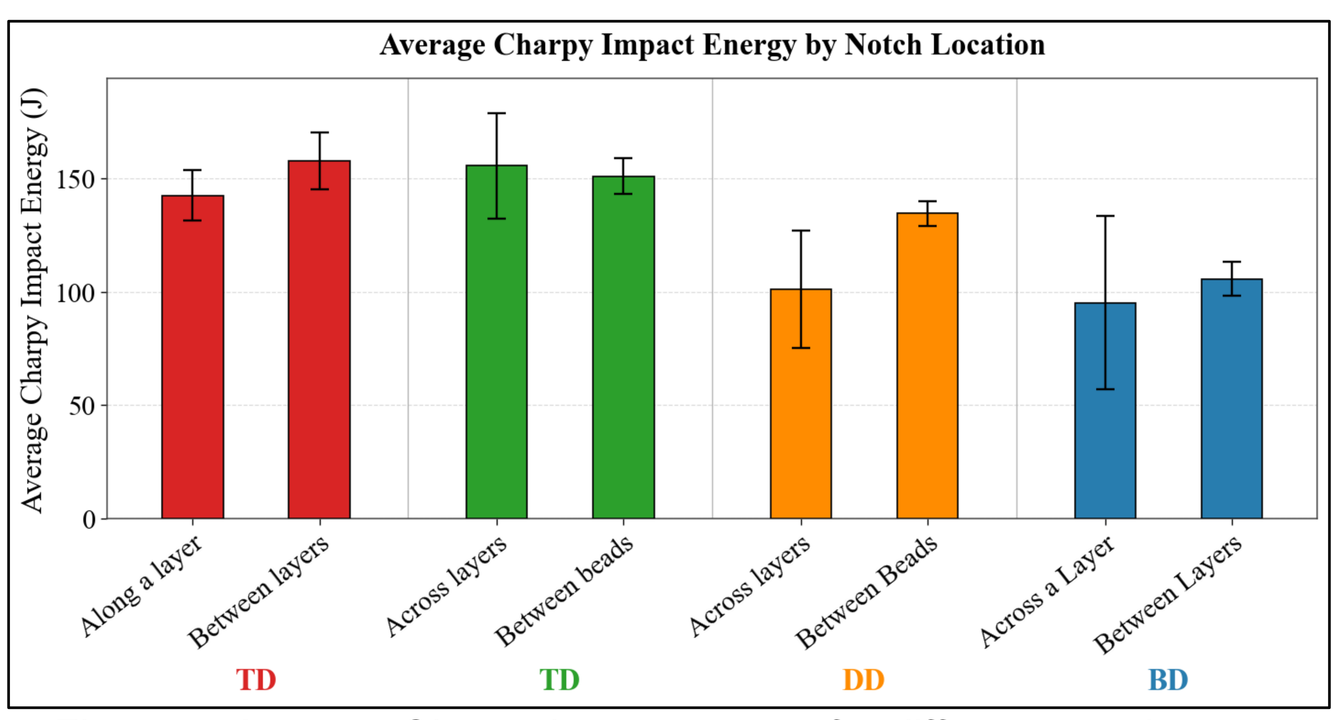


Figure 7: Average Charpy impact energy for different specimen orientations and notch locations within the WAAM build.

- Specimens with crack propagation along the TD consistently exhibited the highest impact energies.
- Differences between notch locations were most pronounced in the DD and BD orientations (orange and blue sets). While effects were comparatively small for specimens with crack propagation along the TD.

Fractography results

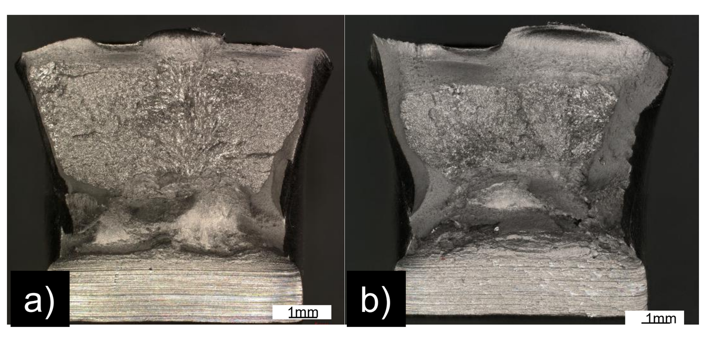


Figure 8: Fracture surfaces a) Orange set 1 b) Orange Set 2.

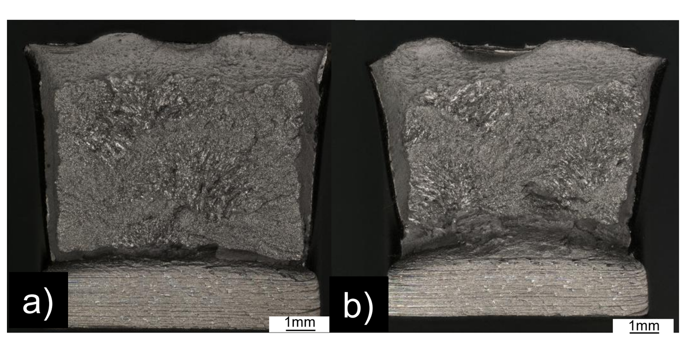


Figure 9: Fracture surfaces a) Blue set 1 b) Blue Set 2.

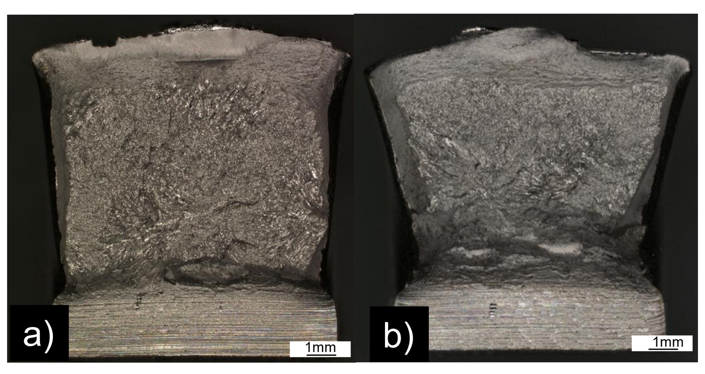


Figure 10: Fracture surfaces a) Red set 1 b) Red Set 2.

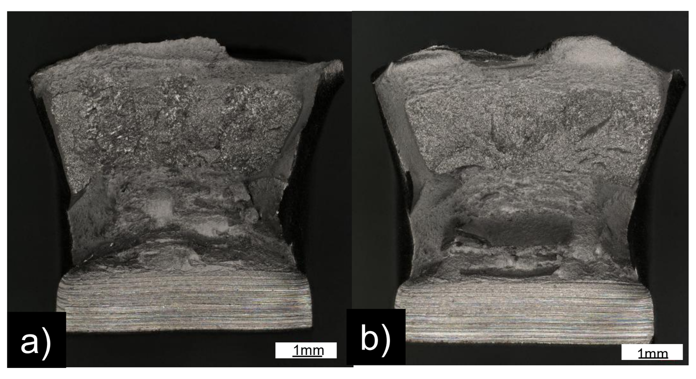
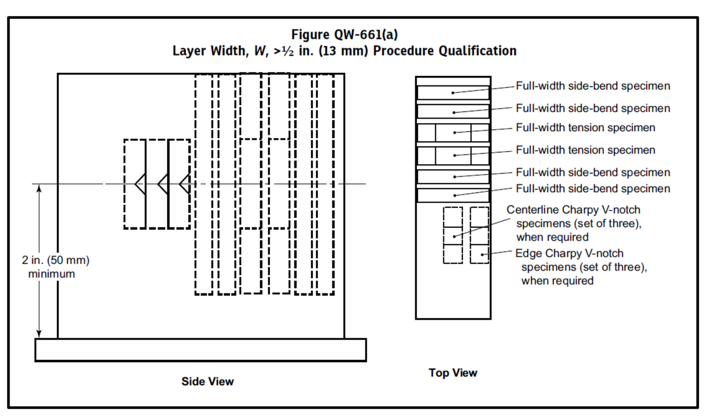


Figure 11: Fracture surfaces a) Green set 1 b) Green Set 2.

- Distinct differences in fracture surface morphology were observed between notch locations within the same orientation
- Fracture paths varied depending on their orientation relative to the solidification direction.

Discussions

- Crack propagation direction strongly influenced CVN toughness



- The ASME Section IX QW-600 qualification orientation corresponded to the higher-energy orientation, suggesting qualification testing may not capture the lowest-toughness direction.

Figure 12: ASME Section IX QW-661(a) specimen extraction locations for WAAM procedure qualification.

Conclusions & future Work

- The current results indicate that both ROI and notch orientation influence the measured impact response.
- The relative orientation between crack propagation and solidification direction appears to influence Charpy impact toughness.
- Upcoming work include:
  - ➢ Verify notch placement relative to the intended microstructure an correlate with impact energies.
  - ➢ Conduct SEM and EBSD on regions of interest to correlate fracture path and impact energies.

Acknowledgments

Industrial Sponsors

This work was done with the support of Lincoln Electric, Apollo-Clad Laser Cladding and the University of Maribor

APOLLO-CLAD Laser Cladding

LINCOLN ELECTRIC

University of Maribor

Contact Information

mtabdull@ualberta.ca
jealvare@ualberta.ca
fcastroc@ualberta.ca
pmendez@ualberta.ca