Enhancing Additive Friction Stir Deposition through Comprehensive Ultrasonic Defect Detection and Process Optimisation

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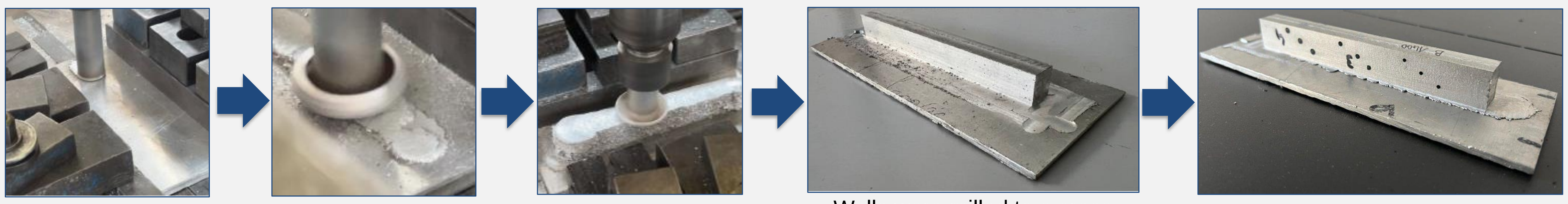
Project Background

Additive Friction Stir Deposition (AFSD) AA2024 aluminium alloy specimens



Substrate (3 mm thick) → Consumable tool (25 mm diameter) → Straight walls (height ~22 mm)* → Walls were milled to a cross section of 20x15 mm (height x width) → Three sets of three holes, 2, 3, and 4 mm in diameter, were drilled at different heights

* Walls built using the parameters on the table, with constant tool feed speed (360 mm/min) and tool force (8 kN)

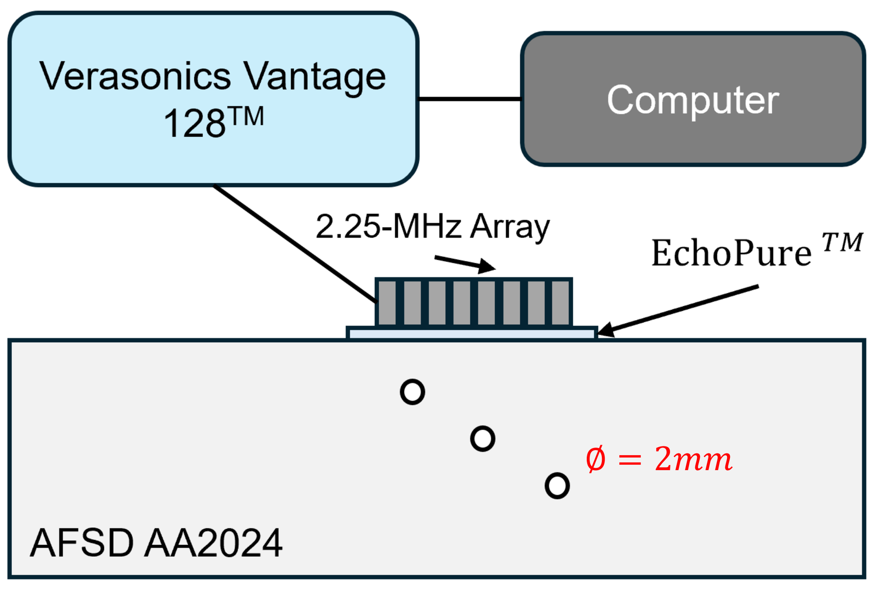
Test specimens manufactured on an ESAB LEGIO machine

ID	Tool Rotation [rpm]	Number of passes
F800	800	10
C1100	1100	15
B1400	1400	20

Solid-state-based AFSD is a promising method towards defect-free additive manufacturing, as it reaches temperatures around half of the material's melting point. This technique is of particular importance in applications of high value, where intricate designs and costly materials are involved. Nevertheless, the challenges of manufacturing process parameters can lead to the formation of various defects. Thus, it is essential to detect and optimise these parameters.

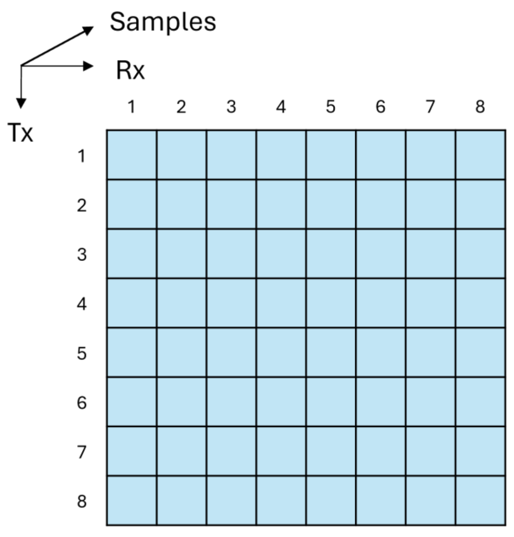
Methodology

Data acquisition: Full Matrix Capture (FMC); Imaging: Total Focusing Method (TFM)



Setup example for the 2.25-MHz array

FMC example for an 8-element array

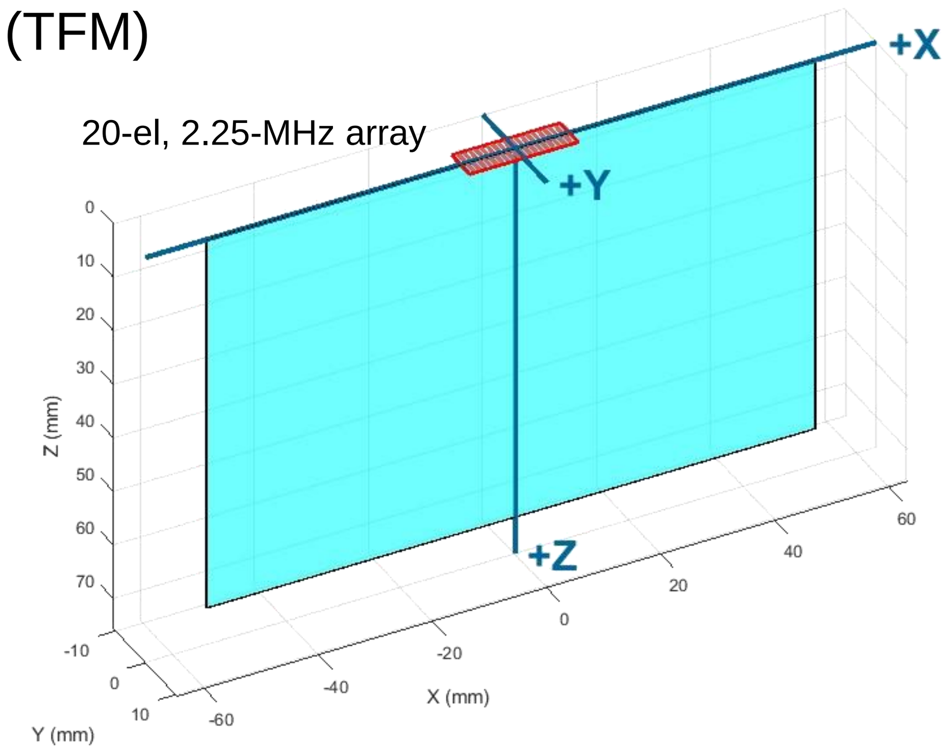


Every combination of Tx/Rx results in a full set of A-scans.

TFM Image intensity [1], $I(x,z)$:

$$I(x,z) = \left| \sum_{tx=1}^{N_{tx}} \sum_{rx=1}^{N_{rx}} h_{tx,rx} \left(\frac{\sqrt{(x_{tx}-x)^2 + z^2} + \sqrt{(x_{rx}-x)^2 + z^2}}{c_l} \right) \right|$$

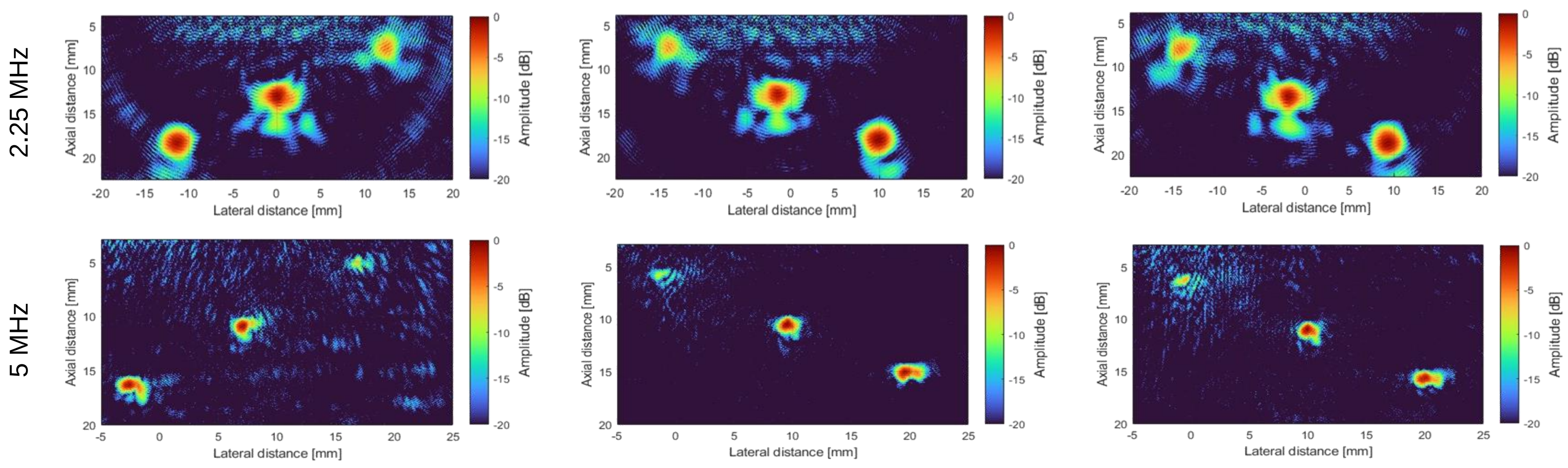
Ultrasonic beam is focused at each point within the target region



Imaging plane example for the 2.25-MHz array

Experimental Results

Ultrasonic imaging and defect detection



TFM images at two different frequencies for the three distinct specimens

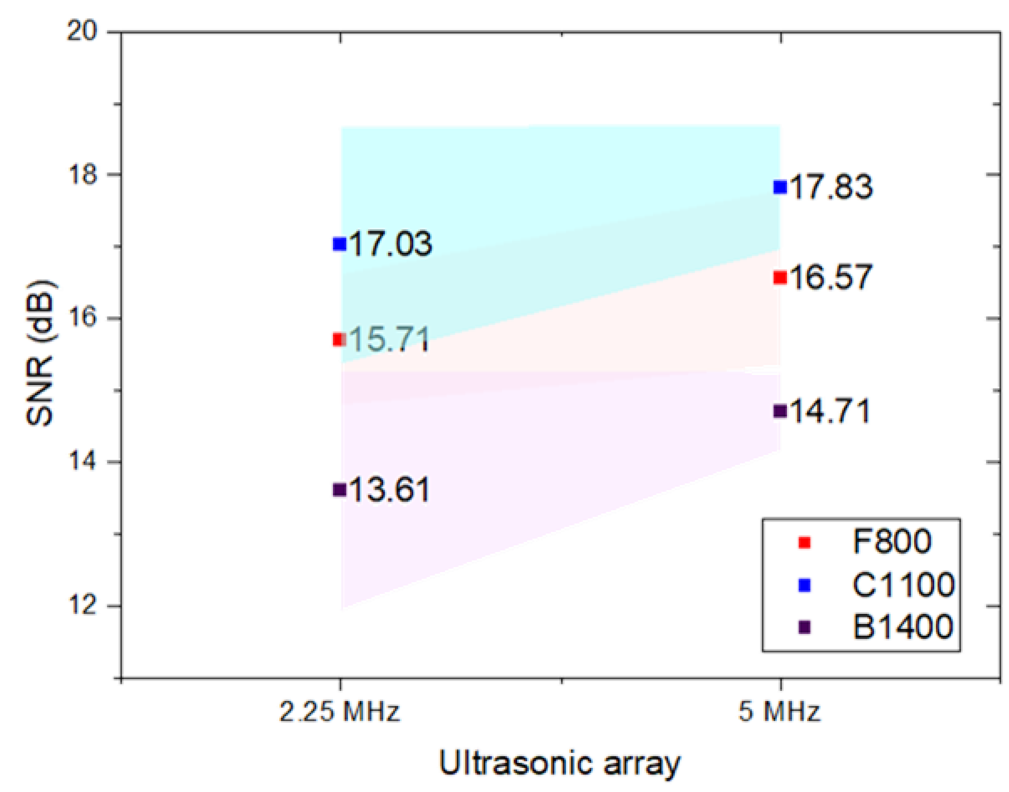
Frequency (MHz)	Acquisition parameters	
2.25	Voltage	40 V
	Gain	10 dB
5	Voltage	50 V
	Gain	20 dB

SNR value [2], SNR:

$$SNR = 20\,log_{10}\left(\frac{A_{max}(r)}{\sqrt{\left(A_{noise}(I_n)\right)^2}}\right)$$

- Standard pulse (1 cycle) employed to excite the array
- Defects were accurately imaged using TFM
- Smallest machined/artificial defect detected at different depths

Signal-to-noise ratio (SNR)



SNR results for the two arrays

- The averaged SNR with the 5 MHz array > the 2.25 MHz array for all cases
- Further improvement in SNR for the 5 MHz array can be obtained by considering the array element directivity pattern

Conclusions & Future Work

1. AFSD AA2024 aluminium alloy specimens were imaged and the smallest targets detected at different depths.
2. Further SNR improvement can be attained by considering array element spread angle.
3. Next Steps:
   a) Further study on smaller targets and crack-shaped unbonded zones.
   b) Explore the application of phase modulated coded signals for improved SNR at different frequencies and conditions.

References

[1] C. Holmes, B. W. Drinkwater, and P. D. Wilcox, "Post-processing of the full matrix of ultrasonic transmit–receive array data for non-destructive evaluation," *NDT & E.*, vol. 38, pp. 701–711, Apr. 2005. DOI: 10.1016/j.ndteint.2005.04.002

[2] Nicolson E, et al. Dual-tandem phased array Method for Imaging of near-vertical Defects in narrow-gap welds. NDT E Int 2023;135:102808.