IMPLEMENTATION OF AN ULTRASONIC TOTAL FOCUSING METHOD FOR INSPECTION OF UNMACHINED WIRE+ARC ADDITIVE MANUFACTURING COMPONENTS THROUGH MULTIPLE INTERFACES

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Outline

• Introduction into Additive Manufacture & Wire + Arc Additive manufacturing (WAAM) & NDE of WAAM
• In-process NDE of WAAM
  o Challenges with In-Process NDE of WAAM
  o High Temperature ultrasound Roller-Probe concept
  o Adaptation of UT TFM Imaging Algorithms for Roller-Probe inspection of WAAM
• Inspection of Calibration Mock WAAM Aluminum sample
• Inspection of Titanium as-built WAAM wall
• Conclusion and Future Work
What is Wire+Arc Additive Manufacturing (WAAM) ?

• WAAM is a large-scale AM technology that employs an arc welding process to produce metal parts additively

How Does it work?

• WAAM works by melting a metal wire using an electric arc/laser as the heat source.
• Melted wire is then extruded in form of beats on the substrate plates to form a part

Key Benefits

• Significant reduction in material needed to produce a part is achieved, therefore a cost is reduced
• Ability to deposit many otherwise expensive materials such as Titanium or stainless steel

Limitations when using WAAM

- Similarly to any arc welding process, defects affecting serviceability of the component can occur.
- Commonly, defects are caused by the lack of fusion, entrapped particles or due to poor deposition parameters and contaminated environment.
- Therefore, Non-Destructive Evaluation must be performed to assess the serviceability of the components.
Ultrasonic Inspection of WAAM components

- Currently, the components are tested either in immersion tanks or after surface machining because of the curved and the rough nature of the WAAM surface.
- Surface machining can significantly add to the process time and cost, while immersion tests may not be practical for very large components.
In-Process Inspection of WAAM components

What it is?
- Method merging manufacturing and NDE into a single process
- Improvement in cost-effectiveness is achieved by detecting defects as they are happening
- Associated with Robotic delivery of NDE

Challenges with in-process NDE of WAAM
- The Inspection equipment needs to be deployed on components with complex geometry and at elevated temperatures
High temperature ultrasound Roller-Probe concept for automated in-process NDE

Developed and built in-house at the University of Strathclyde

The Roller-Probe design consists of:

- UT phased array Transducer mounted on the top of high temperature resistant solid core (Delay Line)
- Rotary, conformable and high temperature resistant rubber wheel
- Suitable for automated NDE
Full Matrix Capture (FMC) & Total Focusing Method (TFM)

Captures Data from every transmit-receive combination in form of 3D Metrix

Key Advantages:
No pre-knowledge of the Sample is required

TFM Image is constructed by summing up signal from each Transmit-receive combination in each pixel based on the calculated Time of Flight (ToF).

$$I(P) = \sum_{i=1}^{N} S_{Tx,Rx} \left( T_{Tx(x,y)} + T_{Rx(x,y)} \right)$$

Advantages:
- Ability to detect smaller defects
- Imaging through multiple Media
Implementation of TFM for Roller-Probe inspection

- The algorithm must consider **3 different velocities**
- The Refraction at 1 flat and 1 curved interface must be considered and Snell’s law justified

\[
\frac{\sin(\theta_i)}{v_1} = \frac{\sin(\theta_r)}{v_2}
\]

- **Ray tracing** is performed using a search algorithm developed, where the point on the 1\textsuperscript{st} interface is chosen and path through is calculated to the depth of the targeted pixel.
- Based on the obtained error between the pixel and incoming ray, the position of the point on the 1\textsuperscript{st} interface is adjusted until maximal accepted error is achieved
Ultrasonic Surface reconstruction

- Dual-Medium algorithm based on Synthetic Aperture Focusing Technique (SAFT) is adapted to reconstruct Rubber Tire/Sample interface.
- The contributing elements to each pixel are limited by predetermined angle
- Amplitude based thresholding is, then, used to automatically select points corresponding to the surface of WAAM. Therefore, reconstructing the surface curvature and measure the compression of the rubber tire.

$$I_{rubber}(P) = \sum_{i=1}^{N} \sum_{j=\alpha}^{\beta} S_{TX,Rx}(T_{TX(x,y)} + T_{RX(x,y)})$$
TFM Inspection of Aluminum Mock WAAM Sample

Results

Auto-reconstructed vs CAD surface profile

1) 1.0 mm Flat Bottom Holes (FBH) reaching 4 mm below the surface

5) 1mm FBH

9) The sample is imaged from 2mm below the surface to the depth of the back

Inspection Setup

- LTPA Array Controller (Peak NDT)
- 5 MHz, 64 element, 0.5 mm Pitch PA Transducer
- 30N Force applied by KUKA Robotic Arm
- FMC data acquired using: 60V, 60dB Gain

Artificial defects: 1.0 mm Flat Bottom Holes (FBH) reaching 4 mm below the surface
Inspection of as-built Titanium WAAM component

**Inspection Setup**

- Titanium WAAM Wall deposited using oscillation strategy
- Artificial defects produced as 1mm and 2mm bottom drilled holes
- LTPA Array Controller (Peak NDT)
- 5 MHz, 64 element, 0.5 mm Pitch, PA Transducer
- 30N Force applied by KUKA Robotic Arm
- FMC data acquired using: 200V, 60dB Gain

**Results**

*The sample is imaged from 5 mm below the surface to the depth of the back wall*
Conclusion and Future work

Conclusion:
• Implementation of 3-Layer TFM algorithm for inspection using a dry-coupled Phased Array Roller-Probe
• SAFT based surface finding algorithm was implemented into the imaging algorithm to detect WAAM curvature
• Artificial defects (1mm FBH) on both Aluminum Mock sample and (1 and 2mm BDH) Titanium WAAM wall successfully detected with minimum 15dB SNR

Future works include:
• Deployment of an alternative signal transmission and reception strategies to enhance SNR of challenging as-built WAAM Components
• Development of automated defect-recognition and auto-calibration algorithms
• Deployment within the WAAM Manufacturing Process
Thank you