In-process Non-Destructive Evaluation of Wire + Arc Additive Manufacture Components Using Ultrasound High-Temperature Dry-Coupled Roller-Probe

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Abstract

In 2019, the global metal Additive Manufacturing (AM) market size was valued at € 2.02 billion and was predicted to grow by up to 27.9% annually until 2024. Additive Manufacturing plays a significant role in Industry 4.0, where the demand for smart factories capable of fabricating high-quality customized products cost-efficiently exists. Wire + Arc Additive Manufacturing (WAAM) is one such technique that WAAM utilizes industrial robotics and arc-based welding processes to produce components on a layer-by-layer basis. is enables automated, time and material-efficient production of high-value and geometrically complex metal parts. To strengthen the benefits, the demand for robotically deployed in-process Non-Destructive Evaluation (NDE) has risen, aiming to replace manually deployed inspection techniques deployed after the full part completion.

The research presents a new synchronized multi-robot WAAM deposition & ultrasound NDE cell aiming to achieve defect detection in-process, enable possible in-process repair, and prevent costly scrappage or rework. Within the cell, the plasma-arc WAAM process, controlled by deposition software, is employed to build components. The full external control NDE approach is achieved by the real-time force/torque sensor-enabled adaptive kinematics control package. A high-temperature dry-coupled ultrasound roller-probe device is employed to assess the structural integrity of freshly deposited layers of WAAM components. The WAAM roller-probe is tailored to facilitate the in-process inspection by dry-coupling coupling with the hot (< 350 °C) non-flat surface of WAAM using a flexible outer silicone tyre and solid core delay-line at speed and at coupling high force[1-3].

The demonstration of the in-process inspection approach is performed on hot as-built titanium (Ti-6Al-4V) WAAM samples. The defect detection capabilities are assessed on artificial tungsten reflectors embedded in WAAM builds. In this work the defect detection is accomplished and analyzed using two separate approaches 1) layer-specific beamforming focusing imaging and 2) volumetric inspection using post-processing algorithms applied on collected Full Matric Capture data. The ultrasound in-process inspection using the dry-coupled roller-probe is driven by live Ultrasound Testing (UT) data acquisition, initiated within a minute from layer deposition completion. The collected UT B-scan frames are based on electronically focused beamforming through the roller-probe media into the depth of targeted layers. Subsequently, the results are presented on a plotted C-scan image, showing a top view over the interior of the targeted built volume. The results in this work are analyzed and compared to the X-ray computed tomography scan, conducted after the full-built completion and sample processing. The processed UT images show positionally accurate detection of embedded tungsten reflectors, with a minimum of 15 dB of signal-to-noise ratio. An accurate size estimation is also achieved for the tungsten defect extended along the sample's length.

The outcome of this research shows a successful defect detection and hence directly supports the industrial benefits of the WAAM process intending to achieve the automated production of first-time-right parts.

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