Investigating Ultrasound Wave Propagation through the Coupling Medium and non-flat Surface of Wire + Arc Additive Manufactured Components Inspected by a PAUT Roller-probe

Muhammad Khalid Rizwan, Rastislav Zimermann, Ehsan Mohseni, Randika K. W. Vithanage, Euan Foster, David Lines, Charles N. Macleod, S. Gareth Pierce, Anthony Gachagan

Department of Electronic & Electrical Engineering, University of Strathclyde, 204 George Street, Glasgow, G1 1XW, UK

Additive manufacturing (AM) has found extensive applications in the design and development industries in the recent years, ranging from aerospace and defence to nuclear sector, for its cost effectiveness, reduced material wastages and better accuracy offered for manufacturing components with complex geometries. In particular, Wire + arc AM (WAAM) is preferred for its high deposition rates, offering reduced lead times for large-scale components manufacturing. However, the quality of a WAAM component is affected by the emergence of inherent defects, mainly lack of fusion and keyhole defects that arise from the high temperature and pressure of the tungsten arc, and contaminations. Therefore, in addition to a high throughput WAAM process, a robust non-destructive evaluation is required to ensure better structural integrity of the component. In this regard, an integrated non-destructive technique can provide early detection of structural discrepancies in the WAAM, hence, preventing component from scrappage and minimizing rework.

Phased-array ultrasonic testing (PAUT) is widely used for volumetric non-destructive inspection of metallic components. The method is well developed where standard tools for numerous experimental conditions have been successfully implemented over the years. A high temperature PAUT roller probe design, with a flexible tire material, has proven to provide dry coupled, in-process inspection of WAAM. The polymeric tire material of the probe is flexible to adapt well to the as-built, non-planar surface of WAAM and can resist the high temperature of the process. However, acoustic coupling between the probe and sample is achieved by applying a high compressive force to the roller probe in a direction normal to the WAAM surface, in the order of 150 N. This creates a nonuniform density profile of coupling medium, maintaining a highly compressed zone in the centre of probe, and reducing toward corners according to the curved surface of WAAM. Consequently, the acoustic velocity in the coupling medium does not remain constant throughout the contact area which gives a variable acoustic refraction along the WAAM surface. For example, as suggested by our measurements, acoustic velocity in the coupling medium under varying compressive force is demonstrated in Figure 1.

UT waves delay and sum (DAS) image reconstruction requires accurate ray racing, thereby relying on correct wave refraction in a multi-layer structure. In fact, when the accuracy of ray tracing for ultrasonic image reconstruction is compromised, the incorrectly delayed and summed acoustic waves reduce the accuracy of shape, location and orientation of defects and their resolution in the obtained images. In this work a mock-up sample, with a surface profile similar to that of a WAAM containing side drilled holes placed at varying distance from the centre of the sample, will be investigated. The dimensions and signal-to-noise ratio of the defects will be analysed in total focusing method (TFM) images obtained with and without accounting for the velocity profile of the coupling medium.

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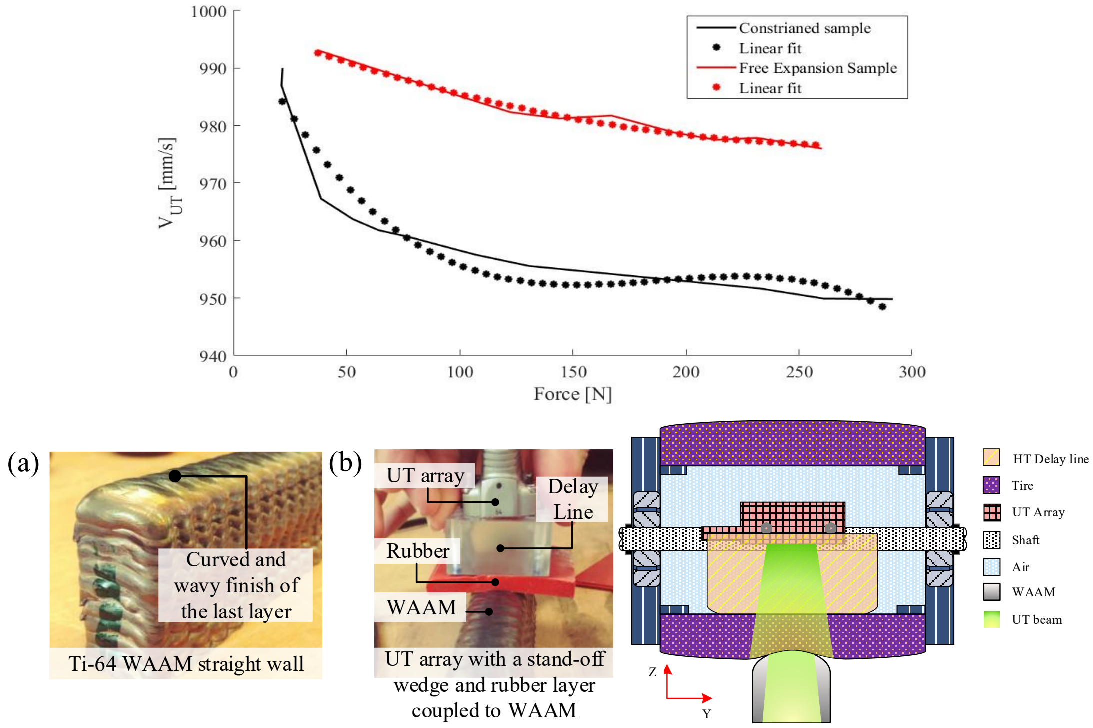

Figure 1. UT velocity (V_{UT}) measured in the coupling medium of PAUT roller probe as a function of applied compressive force, when the material is constrained from expansion (black curve) and when the material is allowed to expand through the sides (red curve). An overview of a WAAM sample and its surface contact with the roller probe