Structural integrity of wire + arc additively manufactured steel components

Researcher(s): Robin Motte
Supervisor(s): prof. Wim De Waele, dr. Dibakor Boruah

Funding organisation: Ghent University's Special Research Fund (BOF)
Start date: January, 2022
Duration: 4 years

Keywords: ***WAAM, additive manufacturing, remanufacturing, sustainability, fatigue, residual stresses***

Motivation

Remanufacturing can be described as the process of returning a used product to at least its original performance. This end-of-life strategy results in reduced cost and energy and materials consumption, therefore contributing to a more sustainable economy. Figure 1 shows an ideal circular economy created by a combination of recycling and remanufacturing, removing wasted materials and the need for new resources.

One possible technique to achieve the dimensional restoration of a worn metal part is Wire + Arc Additive Manufacturing (WAAM). As metal wire is fed into an electric arc, new metal is deposited onto the substrate layer by layer. This process offers a high deposition rate and material usage efficiency, however, there are major challenges related to the structural integrity of the remanufactured component. Because of the high heat input during the process, considerable residual stresses occur, which can cause significant deformation or premature failure during deposition. Additionally, there is a strong heterogeneity in the microstructure and mechanical properties at the interface of the substrate and the deposited metal.

Objectives

In order to gain insights into the structural integrity of steel components remanufactured by WAAM, the main aspects of this research project are:

1. Characterisation and analysis of residual stresses
2. Characterisation of the interface between WAAM deposit and substrate
3. Effect of post-deposition treatment

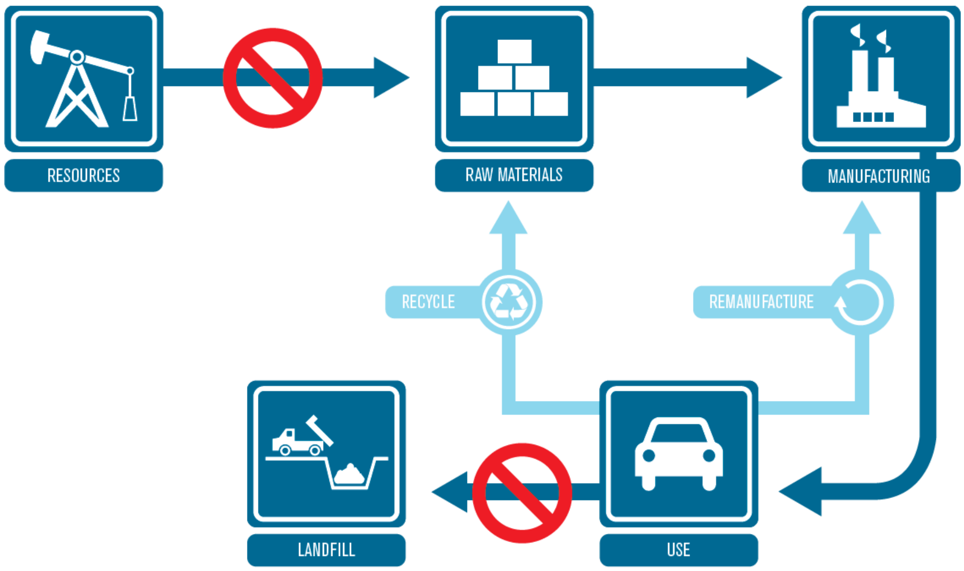

Figure 1: Remanufacturing: the route to a closed-loop system (source: A report by the All-Party Parliamentary Sustainable Resource Group, Remanufacturing: Towards a Resource Efficient Economy, 2014)

GHENT UNIVERSITY
SOETE LABORATORY

APPROACH

1. Characterisation and analysis of residual stresses

A novel technique based on Digital Image Correlation (DIC) combined with finite element simulations will be developed to allow the calculation of residual stress distributions. Figure 2 schematically shows DIC used to capture the deformation resulting from unclamping a specimen after deposition. From these strain measurements, the residual stress distribution can be calculated through reverse engineering. The novel DIC-based technique will be benchmarked against two established techniques: neutron diffraction and incremental hole drilling. The feasibility of extending this technique to monitoring deformations induced throughout the WAAM process will also be explored. In order to characterise residual stress gradients with more detail, a DIC-supported slitting procedure will be developed. Experimental data of small samples will be used to calibrate a finite element model (FEM) which will allow the prediction of residual stresses in a large-scale structure. Analytical models will be used as validation for simple configurations, while final validation will be based on experimental measurements.

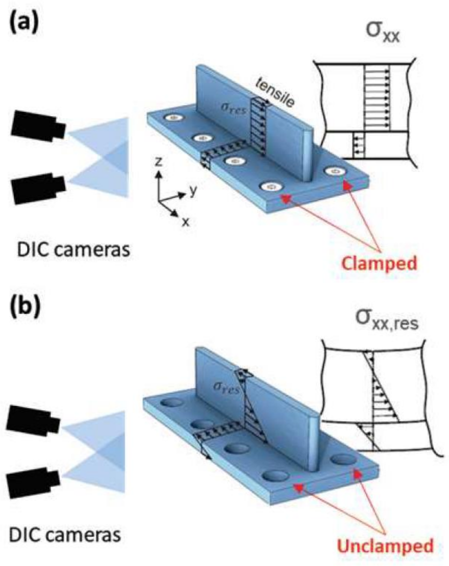

Figure 2: Capturing deformation using DIC through comparing (a): clamped state: unbalanced stress field developed during deposition, (b) unclamped state: distortion leading to redistributed and self-balanced stress field

2. Characterisation of the interface between WAAM deposit and substrate

Optical microscopy and scanning electron microscopy will be used to investigate the microstructure at the interface between the substrate and deposited material. Mechanical properties will be characterised through microhardness, tensile, toughness and fatigue testing. Figure 3 shows the extraction locations of dogbone test specimens. During tensile testing, DIC will be used to evaluate potential strain inhomogeneity, and infrared thermography will be used during tensile and fatigue testing in order to trace (sub-) surface damage. Based on the microhardness distribution, element-specific properties will be assigned in the FEM, which will be validated using the tensile test DIC data. A novel fatigue life model will be developed, taking heterogeneous microstructural properties into account.

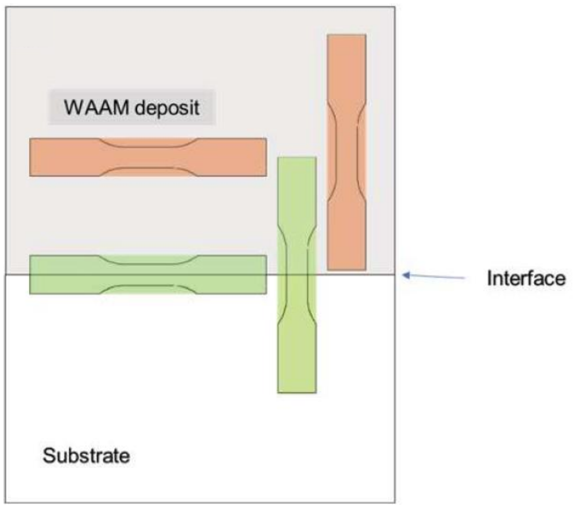

Figure 3: Orientation of dogbone test specimens in the WAAM remanufactured part (green: characterisation of interface; orange: characterisation of deposit)

3. Effect of post-deposition treatment

Post-deposition heat treatments are conventionally applied in order to improve microstructural homogeneity and relieve residual stresses. However, this technique is challenging and costly for large components and can introduce thermal distortions. Therefore, the feasibility of a pneumatic impact treatment to improve mechanical performance will be investigated.

Contact Details

Researcher(s):

Robin Motte robin.motte@ugent.be; Bibliography

Supervisor(s):

prof. Wim De Waele wim.dewaele@ugent.be; Bibliography

dr. Dibakor Boruah dibakor.boruah@ugent.be; Bibliography