CHARACTERIZING DOT-BY-DOT STEEL WAAM BARS USING CT, 3D SCANNING AND MECHANICAL TESTS

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ABSTRACT

This study focuses on the dot-by-dot deposition strategy in Wire Arc Additive Manufacturing (WAAM) technology, which consists of depositing molten metal droplets, creating line-type elements well-suited for large-scale and complex lattice structures. The study analyzes the geometric irregularities and internal defects in bars with varying nominal diameters, build angles (inclination concerning the vertical axis), and printing parameters. It evaluates their impact on mechanical performance via the results of Computed Tomography (CT) and high-resolution 3D scanning. Mechanical tensile tests were performed on the bars to have an idea about the key mechanical parameters, enabling the evaluation of the influence of geometric irregularities on the mechanical performance.

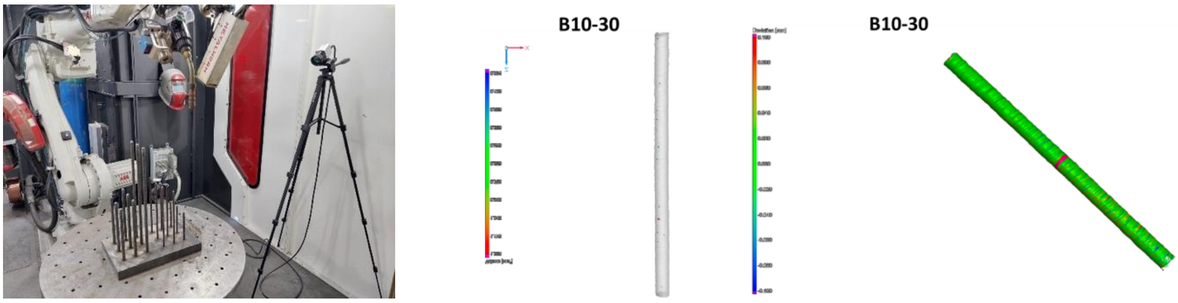
Keywords: Wire arc additive manufacturing, dot-by-dot deposition, porosity analysis, computed tomography

1. INTRODUCTION

Wire Arc Additive Manufacturing (WAAM) technology stands out for its potential in the Architectural, Engineering and Construction (AEC) sector, primarily due to its ability to manufacture large-scale metallic components. WAAM is particularly advantageous for producing complex and sizable structures with higher structural efficiency, enabling material optimization and waste reduction while minimizing environmental impact. However, research has shown that WAAM-fabricated elements exhibit distinct material and structural behaviors compared to conventionally manufactured components, emphasizing the need for further investigation into their properties, which are influenced by the specific parameters used during the WAAM process (Laghi et al., 2022; Silvestru et al., 2021). In this study, the focus is on dot-by-dot steel WAAM bars, produced through the sequential deposition of molten metal droplets, suitable for line-type elements. Particular attention is given to assessing the geometric irregularities and internal defects (i.e., porosity) of the bars and their influence on mechanical performance. The analysis is carried out on bars manufactured with varying process parameters, two nominal diameters (i.e., 6 mm and 10 mm), and two build angles (i.e., 0° and 30°), representing the angle between the longitudinal axis of the bar and the vertical axis, perpendicular to the base plate.

2. MATERIALS AND METHODS

The bars were fabricated by MetalWorm using the dot-by-dot deposition strategy employing a MHTTN-1000 WAAM system. This system integrates an ABB IRB4600 robotic arm for precise deposition and a 2-axis positioner, which was not utilized in this experiment. A Fronius TPS 500i CMT power source provided the energy for the deposition process. The bars were printed onto an S355JR steel substrate using ER70S6 SG2 steel wire as the feedstock material. A mixture of 82% Ar + 18% of CO_2 is used as shielding gas with 18 L/min flow rate. Also, both gas pre flow and gas post flow are set to 1.5 seconds. The manufactured bars (shown in Fig.1a) consist of a total of 12 specimens, which are all 200 mm in length and are classified into four categories based on their nominal diameter and build angle as follows: 3 bars with a nominal diameter of 6 mm and a build angle of 0° (B6-0), 3 bars with a nominal diameter of 10 mm and a build angle of 0° (B10-0), 3 bars with a nominal diameter of 6 mm and a build angle of 30° (B6-30), and 3 bars with a nominal diameter of 10 mm and a build angle of 30° (B10-30). The experimental campaign consisted of Computed Tomography (CT) and high-resolution 3D scanning techniques for the geometric characterization and defect analysis of the bars (see Fig.1b) and then performing tensile mechanical tests for the mechanical characterization of the bars. To validate the reliability of the CT-derived models, a comparative analysis was performed against the geometries obtained through high-resolution 3D scanning, validating the consistency and precision of the results as shown in Fig. 1c. Subsequent mechanical characterization was performed through tensile mechanical tests in displacement control mode. A linear deformometer with a gauge length of 50 mm was employed to measure the strain of the specimens up to the yield point. Stress-strain curves, derived from the tensile tests by assuming the volume-equivalent cross-section as the resistant cross-sectional area, were used to evaluate key mechanical parameters, according to the procedure adopted also in (Laghi et al., 2022).



(a) (b) (c)

Figure 1: Test bars: a) Printed Bars b) Porosity Result of ∅10mm c) CAD Comparison of ∅10mm

3. RESULTS AND DISCUSSIONS

All 24 bars were printed with defined dimensional stability. The results of the porosity analysis were confirmed by the outcomes of the tensile mechanical tests, revealing a strong correlation between theporosity ratio and the mechanical behavior of the WAAM steel bars. Three distinct porosity ratio ranges were identified: less than or equal to 0.05%, between 0.05% and 1%, and greater than or equal to 1%. Specimens in the first category (porosity ratio ≤ 0.05%), corresponding to the batches B10-0 and B10-30, exhibited a ductile behavior, characterized by a well-defined yield point and substantial plastic deformation prior to fracture. In contrast, the specimens within the second category (0.05% < porosity ratio < 1%), represented by the batch B6-30, demonstrated a less ductile response, with a reduced capacity for plastic deformation and a less pronounced yield point. Finally, specimens with a porosity ratio exceeding 1%, corresponding to the batch B6-0, displayed a brittle mechanical behavior, where failure occurred shortly after the elastic limit with minimal or no plastic deformation.

4. CONCLUSIONS

Dot-by-dot bars can be produced with WAAM at higher dimensional stability. The results have shown the influence of porosities on the mechanical performance of WAAM steel bars, demonstrating a strong correlation between porosity and material properties, emphasizing the need to control the melt pool shielding, solidification rates and process parameters.

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