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DEVELOPMENT AND CHARACTERIZATION OF A HIGH-STRENGTH LOW-ALLOY 2.5CR-1MO STEEL COMPONENT PRINTED VIA ADDITIVE MANUFACTURING WITH WIRE AND ARC

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Abstract: Additive manufacturing has been recognized as an alternative manufacturing technique for industrial sustainability by obtaining components with geometry close to the final shape, on-demand production and synthesis of post-processing steps, reducing material waste, manufacturing costs and CO_2 emissions. In this sense, the objective of this work was to develop an additive manufacturing component with wire and arc for application in the context of the oil and gas industries. Studies of process parameters and deposition trajectories were carried out, followed by computational simulation, microstructural, mechanical and corrosive characterization. It was concluded that the printed materials presented properties within the standards requirements and properties equivalent or superior to their counterpart manufactured via forging.
Keywords: additive manufacturing, production on demand, sustainability, wire and arc.

INTRODUCTION

Seen as one of the main pillars of industry 4.0, additive manufacturing with wire and arc is a manufacturing method based on 3-dimensional models, which follows a layer-by-layer deposition sequence [1,2]. This manufacturing technique has been recognized as an ideal alternative for sustainable industrial development by obtaining components with geometry close to the final shape, production on demand and synthesis of post-processing steps, reducing material waste, costs and CO_2 emissions [3]. Furthermore, the already consolidated knowledge of welding processes allows the production of high-resistance and low-alloy steel parts via additive manufacturing with a microstructure analogous to the weld metal, a region in which the best mechanical properties and microstructural refinement are available, justifying the replacement of materials produced via forging with printed materials [4].

MATERIALS AND METHODS

The first step in manufacturing the component was the development of deposition and trajectory parameters based on the design of 2^k factorial experiments for parameter selection. The GMAW-CMT transfer mode was used. With a view to the best selection of parameters, the CAD model of the preform was developed and the deposition trajectory was planned for the development of the deposition code, followed by printing the part using the Kuka robot and Fronius welding source. With the part deposited, the stress relief heat treatment was carried out, with a plateau temperature of 675°C for 3 hours in accordance with the ASTM A 182 standard for forged materials of class F22, whose chemical composition is analogous to that of wire ER90S – B3 used in this study. Followed by machining for finishing, non-destructive testing (x-ray), microstructural evaluation, mechanical characterization (traction – ASTM E8/E8M, Vickers hardness – ASTM E92, Charpy impact – ASTM A370 and CTOD – ASTM E1820/ASTM E1290) and evaluation of susceptibility to stress corrosion cracking – NACE TM0177. The desired properties were based on the requirements of API 6A, GFS SU.85.20.03, DNVGL-RP-0034 and NACE TM0177 and had their performance compared with a forged part of type ASTM A182 - F22. In parallel, a thermodynamic simulation of the CCT diagram was carried out with JMatPro software to measure the chemical composition. The component development steps are outlined in Figure 1

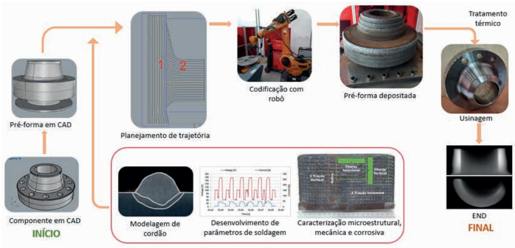

Figure 1 – Component development steps via WAAM.

RESULTS AND DISCUSSION

From the printing methodology outlined, as a first result, it was found that the manufacturing method in passes with an oscillating trajectory presented better metallurgical properties and absence of macroscopic and microscopic defects, such as inclusions, pores or lack of fusion that could compromise the performance of the piece, contrary to what was presented with the trajectory in parallel passes. Such deposition characteristics are shown in Figure 2.

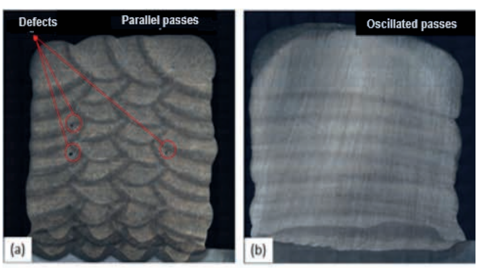

Figure 2 – Printing (a) parallel passes and (b) oscillating passes.

Microstructurally, all depositions stabilized a bainitic microstructure, in accordance with the previously simulated CCT diagram as shown in Figure 3.

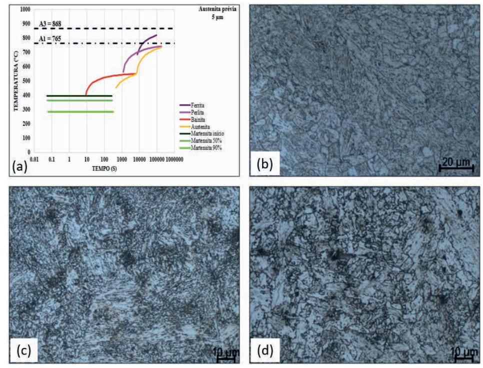

Figure 3 – Microstructural characterization with (a) CCT diagram simulation, (b) micrograph of the forged material, (c) micrograph of the as-deposited WAAM, (d) micrograph of the heat-treated WAAM.

The mechanical properties of the printed part, the forged material and the requirements used to qualify the parts in the field are shown in Table 1, in which the efficiency of the manufacturing process via additive manufacturing for the selected material can be seen, which achieves the required properties, making it a more economical alternative production route for the oil and gas industry.

	Requirements (Standard)	Wrought	WAAM
Yield limit [MPa]	Min. 517 (API 6A)	640	697
Resistance limit [MPa]	Min. 655 (API 6A)	750	775
Stretching [%]	Min. 15 (API 6A)	25,8	22
Vickers hardness [HV10]	197-250 (API 6A-min e NACE MR 0175-máx)	235 ±6,08	238 ± 4,52
Impact toughness at 46°C [J]	Min. 42 (GFS SU.85.20.03)	213	129
CTOD [mm]	Min. 0,25 (DNVGL-RP-0034)	0,52	0,35
Four-point flexion in 100% H2S medium - NACE TM0177	Approved. Absence of surface cracks.	Approved	Approved

Table 1– Mechanical properties of materials in forged and printed condition.

CONCLUSIONS

It is concluded that additive manufacturing is a promising manufacturing technique, with the possibility of developing metallic components with properties equivalent or superior to those obtained by traditional manufacturing methods at a lower production cost. For high-resistance and low-alloy steels, especially the composition worked in this study, it is concluded that the parts are not limited by environmental conditions, presenting properties that allow their applicability in the field.

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