Wire and Arc Additive Manufactured Materials Corrosion Behaviour

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Wire and Arc Additive Manufacturing (WAAM) is a deposition rate process for the creation and/or repair of large structural metallic components. The non-equilibrium heating and cooling conditions associated with WAAM lead to the development of heterogenous microstructures. Although there is a large body of work focusing on the microstructure and mechanical properties of WAAM-fabricated components, assessment of the corrosion behaviour of alloys fabricated by WAAM is still in its infancy. Here, the body of knowledge associated with the corrosion behaviour of different WAAM-fabricated engineering alloys is presented and discussed. Future perspectives and potential research topics are also presented. This is the first work focusing on the corrosion of wire and arc additive manufactured materials.

Keywords: wire and arc additive manufacturing ; corrosion ; microstructure

1. Introduction

Metallic materials are part of day-to-day life as they are key in the improvement of living conditions around the world. Conventional manufacturing processes for metallic materials allow to create multiple components, but often there are design limitations imposed by the manufacturing process itself. The advent of additive manufacturing (AM) allowed for complex-shaped structures to be easily fabricated in a layer-by-layer fashion and for the construction of complex geometries with satisfactory accuracy [1]. Although AM processes can be applied to any class of engineering materials [2][3][4][5], metal additive manufacturing is currently expanding given the potential applicability prospects associated with the combination of high strength metallic alloys with improved design flexibility enabled by AM processes. Although most AM processes for metallic materials are focused on the fabrication of small- to medium-sized components, there is a significant and urgent need for processes capable of fabricating larger complex-shaped structures in a timely fashion, while decreasing material waste. With regards to this, within the field of metal additive manufacturing, wire and arc additive manufacturing (WAAM) has a large deposition rate and is known for its low implementation costs and easy maintenance [6]. WAAM is already being used in the industry field for multiple applications, ranging from the repair of obsolete metallic components to the fabrication of new parts, as well as in the oil and gas, energy and aerospace industries [7][8][9][10]. In WAAM, the large heat source can be based on gas metal arc welding (GMAW) [11][12][13][14][15], gas tungsten arc welding (GTAW) [16][17][18][19], or plasma arc welding (PAW) [20][21][22][23][24]. The selection of each of these types of heat sources will influence the microstructure development, process stability, deposition rate, implementation costs and industrial uptake.

Currently, WAAM of different engineering alloys is primarily focused on determining the evolution of microstructure and the resulting mechanical properties [25][26][27][28][29][30][31]. Determining the relationships between microstructure and mechanical properties is currently fundamental since the application prospects of WAAM-fabricated components is for them to be used in structural applications. Hence, it is necessary that how the weld thermal cycle impacts the microstructure along the deposited material is understood so that one can develop new processing conditions or post-process heat treatments, targeting an improvement in the resulting mechanical properties. Despite the importance of linking processing conditions to microstructure and mechanical response, there are other key material features that must be comprehensively assessed to further expand the use of WAAM in key industry sectors where the materials are in contact with aggressive environments, such as in the oil and gas and nuclear industries [28][32]. A key topic that has been lacking attention, with scarce literature to be found on it, is the assessment of the corrosion behaviour of WAAM-fabricated components. There is a fundamental need to address the corrosion behaviour of components built by WAAM as the type of applications associated with this technology, namely large metallic components for critical application in the oil and gas, maritime and aerospace industries, often require that the components be used in demanding, aggressive environments. More importantly, it is well-known that the thermal conditions within a part fabricated by WAAM are dependent on the location of the part. Since there is often a correlation between the thermal cycle experienced by the material and the resulting microstructure (coming from the solidification structure or due to solid state transformations imposed by repeated subsequent depositions), the thermophysical properties, including corrosion behaviour of the fabricated component, can be spatially dependent, which can aggravate the deterioration of the structural integrity during the operation of the component.

2. Corrosion Behaviour in WAAM Materials

Corrosion is defined as a spontaneous reaction that results in material degradation as a result of its interaction with the environment [33]. The material's susceptibility to corrosion is a parameter that depends on different factors, including the corrosive environment, the chemical composition of the material, heat treatment, microstructure, surface finish, production and processing methods [34][35].

When addressing wire arc additive manufactured (WAAMed) materials, some of the process parameters, such as travel speed, wire feed rate, current, deposition path and protection gas flow rate [36][37], significantly affect the resulting microstructure and surface finish and, thus, will have an observable impact on the corrosion behaviour, as previously mentioned. This multiple-parameter effect leads to difficulty in determining their isolated influence. Despite this issue, some authors suggested that a synchronous effect can be condensed and analysed in terms of heat input [38][39].

Compared to conventionally produced methods, AM components present complex microstructures because of the different time-dependent temperature profiles and process parameters [40][41][42][43][44][45][46][47][48]. These microstructures are formed by a combination of rapid solidification rates and high thermal gradients [49]. These processes are known to produce complex, non-equilibrium microstructures with poor surface finish, resulting in the necessity of post-processing treatments. Dinovitzer et al. [38] reported an increase in surface roughness with higher travel speeds and presented an inverse behaviour relative to the current applied during the WAAM process, leading to an increase in corrosion susceptibility [50][51].

Another important factor inherent to this process is the segregation of alloying elements, which is a result of different concentrations and solidification times of the dendritic and interdendritic regions, leading to chemical heterogeneities creating large cathodic regions enabling localised corrosion [52][53].

Despite the increasing attention WAAMed materials are attracting, there is still a lack of information in the literature concerning its corrosion behaviour [54][55][56], which is of fundamental importance prior to a massive industrial application of these materials into industrially relevant settings. During 2018 to 2022, Laser Power-Bed Fusion (L-PBF) corrosion presented twice as much research works [57]. Despite the increase in the number of papers, these studies focus on specific topics related to a particular problem and/or application rather than seek a general comprehension of the corrosion susceptibility [8][25][28][58][59][60][61][62][63][64][65][66].

3. Outlook

Table 1 presents a summary of the effects of the WAAM process on the corrosion susceptibility of the studied alloys. The most common parameter that affected the resistance was the creation of micro-galvanic cells due to solute segregation, emphasising the importance of homogeneous chemical composition within the fabricated material.

Table 1. Summary of the effects of WAAM Process Variables on the Corrosion Susceptibility.

Variables	Effect on Corrosion Susceptibility	WAAM Systems Affected
Solute Segregation	Micro-galvanic cells are created, resulting in localised corrosion [67][68] and different phases along the deposited layer, resulting in distinct corrosion potentials [69].	316LN ER70S-6 10CrNi3MoV

Variables	Effect on Corrosion Susceptibility	WAAM Systems Affected
Refined Grain Size	This variable is still controversial in the literature. Some authors relate coarse and non-equiaxed grains with hindered corrosion behaviour [69][70], while others observe the opposite [68].	10CrNi3MoV 825 alloy TI-6Al-4V
Heat Input	Lower corrosion potentials were observed when applying high heat input [67][69].	10CrNi3MoV 316LN
Current Source	WAAMed materials fabricated using a pulsed current source presented more positive corrosion potentials when compared to constant current sources [71].	SUS 304

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