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Integration of Environmental Assessment in Process Engineering of Metal Additive Manufacturing Technology

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Abstract. Lately researchers have been paying more attention to the environmental aspect, especially since our planet is nowadays threatened by multiple phenomena. In this context as a manufacturing process, the additive manufacturing appeared as a trend in its domain because it's economic, eliminates raw material waste and allows to make complex shapes, which may not be obtained by conventional manufacturing processes. There are many additive manufacturing processes, this research will focus only on Wire Arc Additive Manufacturing which has an impact on the environment, by consuming energy (for welding, for cooling, moving the nozzle…) and gases. In this paper will provide an overview to the different studies related to the environmental aspect of this process, where some have concentrated on the parameters that surround the product, other studies focused on the parameters related to the process. We will group all the ideas to find an application of the process in the context of sustainable development.

Keywords. environmental aspect, additive manufacturing, WAAM.

1. Introduction

Lately the awareness of the importance of the environment is becoming more and more widespread given the importance of the planet to conserve resources, therefore the conservation of resources, and the protection of the planet are becoming more and more the purpose of some researchers and industrials, who are trying to join the modern market.

Nowadays, one of the major issues threatening the environment is Global warming caused by the emission of greenhouse gases due to human activities, studies have proven that one of the major factors of this phenomenon is the industrial sector. Global warming is known by the growth of the global average temperature. According to [1] the increase of global warming keeps growing. It is essential to control and limit greenhouse gas emissions to stop this phenomenon.

Based on a review of the literature, we have extracted the different parameters that can lead to an environmental impact of the WAAM process. therefore, we have identified the most recognized methodology for impact assessment, the second part is a bibliographic study on the different metal additive manufacturing processes, after we explored the WAAM process and its environmental aspects, and in the discussion part we have developed a new model allowing us to identify more clearly the parameters that can be hidden or that we will not be able to know the source.

2. LCA as a methodology to evaluate the environmental impact

There are many environmental assessment tools, but the most recognized is life cycle assessment (LCA).

LCA is a tool based on the international standards ISO 14040-44 to evaluate the environmental impact of processes and products during all phases of their life cycle, from the extraction of the raw material until the end of life of the product [2]. Each product has 4 phases of life cycle: Extraction of raw materials from the environment, the production/manufacturing of the product, the use phase and end of life of the product.

There are different LCA software classified according to their field of use: research, industrial and for experts or consultants.

The most recognized and best-selling software on the market are: SimaPro, NIRE-LCA, LCAIT and Umberto.

As this article will be a preparation for an in-depth study of the WAAM process using the SimaPro software. Therefore, the parameters that will be useful for the use of the software will be studied as well as their impact on the environment.

2.2 Environmental indicators

To assess the environmental impact of metal additive manufacturing processes in general, it is essential to know which environmental indicators must be considered in the study.

Indicators are used to evaluate the impact of the process on the environment.

The emission quantification methods are grouped into two categories: Midpoint and End point.

MID POINT indicators are problem-oriented and END POINT indicators are damage-oriented. There are 18 intermediate indicators (midpoint indicators) and 3 final indicators. Research has proven that the choice of the evaluation method influences the results found, that's why there is always uncertainty between the analyzes of the same technology made by different methods. The study that will continue will be based on the environmental indicators that concern the WAAM process.

3. State of the art

With the development of AM, metal additive manufacturing appeared as a transition from analog to digital processes to manufacture metallic end-use objects (not just to make prototypes). It needs a computer-aided-design software to control how the hardware deposits the material layer by layer according to a well-defined trajectory.

The latest research in the field of additive manufacturing has shown that this new technology in addition to the advantage that it allows to manufacture complicated parts [14, 4] it has multiple environmental advantages. Indeed, many studies have shown that AM is less impactful to the environment if compared with conventional processes, including [5-11]. [12, 14, 15] have shown well in their work that AM consumes less energy and emits less CO_2 into the air. This idea was also evocated by [13] in their work concerning the prospects for the sustainability of 3D printing technologies. [5-6-13-16-17] cited that AM processes are also known by the economy in terms of use of raw material so less waste then less pollution. In their work for estimating and optimizing the environmental impacts of AM processes, [18] demonstrated that the environmental impact differs according to the scenario and trajectories of manufacturing. [19] found that it is necessary to take into consideration not only the trajectory but also the energy consumed by each type of machine to use (eg : to manufacture a part by a single trajectory per layer, using a first nozzle (Macro CLAD) requires 3kW of laser power if using a second nozzle (MesoCLAD), the part is produced by 5 trajectories per layer, the laser power used is 250W). The methodology evoked in their study, [19] consisted in determining the global environmental impact of apart from the CAD model by extracting the parameters from the generated G-code so we can assess many strategies and we decide which one is least impactful. The work does not only focus on electricity consumption but also on the consumption of fluids and materials. In [20] an environmental study to compare electron beam melting (EBM) and rotation of Ti-6Al-4V pieces was elaborated. [25] performed an LCA of Ti-6Al-4V parts to compare direct additive laser manufacturing (CLAD) and machining. Also [21] evaluated the cumulative energy of conventional machining and EBM to manufacture an aeronautical turbine composed of 13 blades. [22] Compared between a binder jetting process and a conventional CNC machining to evaluate the environmental impact of fabricating an engine bracket by binder-jetting process. Concerning powder-based direct energy deposition (DED) methods, [24] presented the first comparative study that evaluates the energy consumption and CO2 emissions related to DMD laser and CNC milling to produce molds and dies.

4. The WAAM technique and its environmental aspects: a literature review

The WAAM technique consists in making a shape by welding layer by layer with a nozzle guided by a robotic arm [26] to obtain the desired shape. The specificity of the WAAM technique is that its working space can be larger than other additive manufacturing processes. Comparative studies between WAAM and other conventional manufacturing methods was made .Additionally, it can show the WAAM technique can significantly reduce the consumption of raw materials and the amount of GHG emissions mentioned in the beginning of the paper. In this context [28] evaluated the environmental impact of WAAM in a comparison to traditional processes to manufacture stainless steel components: green sand casting and CNC milling. According to [29] who evaluated the energy efficiency of WAAM in order to produce a NACA air foil, only two papers have addressed the environmental characterization of WAAM. Jackson et al. compared between the WAAM process and the Jackson powder process, while Bekker and Verlinden recently presented a comparative LCA analysis between the WAAM process, sand casting and Bekker milling. After making his study [29] found that an integrated additive (WAAM)-subtractive manufacturing is the best way to save material and primary energy with respect to traditionally applied approaches. All major resources required (e.g., energy and materials) have been considered, as well as the benefits arising from the recycling of materials. Jianing, (2012), proposed a feature-based cost estimation model and GHG emission model for the WAAM process. Then implemented the model in a plugin integrated into the CATIA software and exploited the possibility of directly extracting geometry data from a CAD file.

5. Results and Discussion

In this section the WAAM process is studied as well as its environmental impact. The transport factor, the use phase and the end-of-life phase will not be considered in this study since it does not depend on the process itself and its impact is the same whatever the process of manufacturing is. We are interested more in the manufacturing phase and the extraction of raw material to be able to highlight the impact of the process.

Parameter	operations
Energy consumption	• Extrusion of raw materiel • Cooling system (to cool layers) • Ventilation • Displacement of the noozle • Melting the metallic wire • Post process operations
Material waste	• Use of specific feedstock materials (support material , metallic material) • Welding spatter
Air pollution	• Extraction of argon to use it as a shielding gas • Gases emitted from fusion of metallic wire • Gases used to extract raw material

Figure 1. The different parameters and their impact

In the fig2. a proposal for the evaluation of environmental impact of the WAAM is presented in the form of an ISHIKAWA diagram. To identify all the possible factors that can influence. The parameters proposed in the previous table fig.1 will be used in-depth study using the SimaPro software to assess the impact of the WAAM process. In some cases, we are forced to manufacture parts by the WAAM process and to carry out post-processing by conventional manufacturing methods, certainly it would be impactful, but we are obliged to proceed with WAAM because some shapes are not possible to manufacture otherwise. It's not possible to think about its impact compared to other processes, indeed some part geometries have hidden details, complex curvatures of small sizes and sharp corners, which makes it impossible to manufacture by a conventional machine, given the absence of precise tools and the limited movements of the machines used during machining. So that topology optimization and the production of generative design parts is more accessible with the WAAM process [32].

In terms of the use of shielding gases some studies have proven that important content of O2 in the shielding gas, provides enough oxides in the weld pool so the arc does not need to search for new oxides on the walls [33].

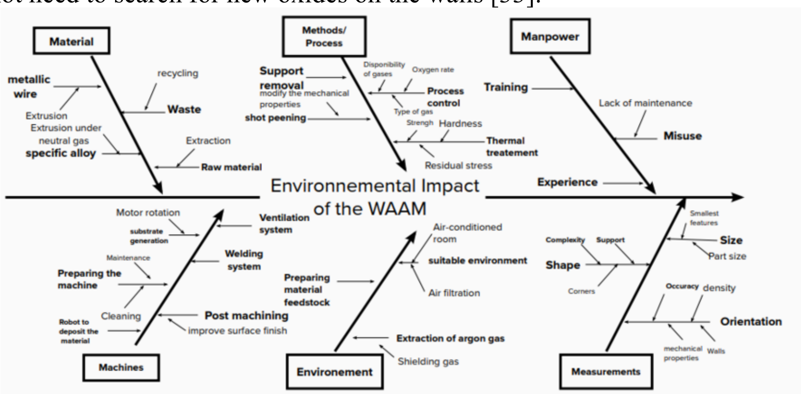

Figure 2. ISHIKAWA Diagram for environmental impact of the WAAM process

6. Conclusion

The present paper has presented the major factors that can have negative impact to the environment and the role that today's processes play in deepening this danger, as well as the methods available for evaluating this impact. A return to additive manufacturing processes and environmental aspects in general has been the objective of the state of the art of this article. The Process WAAM was the object of this paper and the study of its impact on the environment as well as the parameters involved, which was explained in the discussion part.

The WAAM process is a recent process, the studies related to its environmental impact are limited, and in fact certain impacts are still unclear and have not been resolved.

Among the perspectives of the process is to add sensors or systems of detection which makes it possible to identify of emissions of abnormal gases also to automate the process by implementing a fault detection system in the production line by WAAM indeed the idea of using a supervision system by artificial intelligence is proposed since it will be able to detect the faults of the state of surface, the residual stress.

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