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Selection of optimal process parameters for wire arc additive manufacturing

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Abstract

This paper is about the optimal selection of process parameters for Wire Arc Additive Manufacturing technology, an emerging solution for additive production of metal parts. In particular, the selection of the process parameters is based on the evolution of the microstructure and on the mechanical properties of the final samples obtained through the successive deposition weld beads of a ER70S-6 steel, according to the AWS legislation. The feed rate and the heat input during the deposition of the weld beads have been varied, in order to understand how the temperature reached by the samples can affect the final product mechanical characteristics. The final cooling has been carried in calm air at room temperature and between the deposition of a weld bead and the following one it has been imposed a pause of 60s. The tests on mechanical properties carried out have been: A full experimental campaign that includes: macrographic observations, micrographic observations and Vickers microhardness. The analysis of these tests has highligthed that by varying the process parameters, the samples do not have substantial differences between them. Instead, a microstructure that evolves from pearlitic-ferritic grains until bainitic lamellae along the vertical direction of the samples has been observed by micrographic analysis and confirmed by microhardness measurements.
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Keywords: Wire arc additive manufacturing; ER70S-6 Steel; Microstructure; Vickers hardness.

1. Introduction

Additive manufacturing techniques (AM) are widely used today in order to builds up products by the deposition of materials layer-by-layer, instead of using traditional processing techniques based on the machining of the raw material. AM is a promising alternative for fabricating components made of expensive materials such as titanium or aluminum alloys, because of the high value of the buy-to-fly ratio. Many techniques have been developed for manufacturing metal structures in AM, such as selective laser sintering [1], direct metal deposition [2], electron beam melting [3], shape deposition manufacturing [4], and wire and arc additive manufacturing (WAAM) [5–7]. According to the different energy sources used for the deposition of the metal, wire-feed AM is classified into three groups: laser based, arc welding based, and electron beam based [8]. Arc welding based AM has the advantages of a lower cost and higher deposition rate, achieved at the cost of lower feature resolution. This is not a problem for most of the products since a following machining operation is often due. Usually, the deposition rate of laser or electron beam deposition is about 2–10 g/min, while for the arc welding technology the deposition rate is about 50–130 g/min [9-11]. In WAAM, the building strategy consists in the deposition of a series of single weld beads, one on the other, alternating pauses of cooling with deposition steps [12]. The following work is based on the deposition of successive layers of low carbon steel. Heating and cooling phases of the process affects the microstructure and the mechanical characteristics of product [13], that have a strong influence on issues like material machinability [14] and fatigue strength. So, it is really

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important to define the effect of process parameters on the final microstructure of the product obtained in order to choose the optimal setup. The process parameters varied within the tests has been chosen in order to vary both the heat input of the process and the heat flux in a specific product area.

2. Experimental

The experimental campaign for the study and the characterization of the specimens obtained by WAAM technique consists in:

- Macrographic Observations
- Micrographic Analysis by Scanning Electron Microscope
- Vickers microhardness
- Surface analysis by confocal microscopy

The test samples were made by depositing successive layers of materials on a low carbon steel substrate. The filler material used is a standard filler for welding structural steels: ER70S-6 designation according AWS legislation. The test samples were made by superimposing 15 layers. A pause of 60s was imposed between each layer deposition, in order to enable a partial cooling of the deposited material. In the execution of the specimens it was maintained a distance of 10 mm between the torch and the work surface. The deposition procedure is shown in figure 1. Figure 2 shows the ID numbers of specimens and their positioning on the substrate. For the construction of the samples it was used a MIG / MAG welding Millermatic 300 (manufacturer: Miller), whose welding torch was moved by a three axes CNC machine. The tests were performed by setting the values of voltage, feed rate and wire feed speed, in order to obtain different values of heat input. In table 1 are reported the values of the process parameters for individual specimens. All the samples are cooled in calm air at room temperature.

Each sample was cut off from the substrate and it was cut in the middle of the superimposed weld beads in order to observe the bulk of the sample. Before the observations and the analysis, each sample was first grinded by P320 emery paper and then polished by three different diamond suspensions: 9µm, 3 µm, 1 µm and finally ultrasonically cleaned in acetone for 10 min to avoid the presence of impurities. The samples were first observed with a ZEISS Axioplan 2 microscope in order to find the characteristic zones of the samples, then each zone of each sample was analyzed with the Scanning Electron Microscope (SEM) Hitachi TM3000. After the macro and the micro analysis, Vickers microhardness measures were performed along the length of each sample, in order to evaluate the hardness from the first layer deposited on the substrate to the last one, with the CV-400DAT micro Vickers Hardness tester, a load of 300g applied for 20s was used. At last, the ripple surface of each sample was detected with the Confocal Leica DCM3D microscope, to calculate the distance between the deepest valley and the highest peak. The ripple surface was calculated with the external surface of each sample and it was elaborated with the LeicaMap software through operations of filling, leveling and filtering.

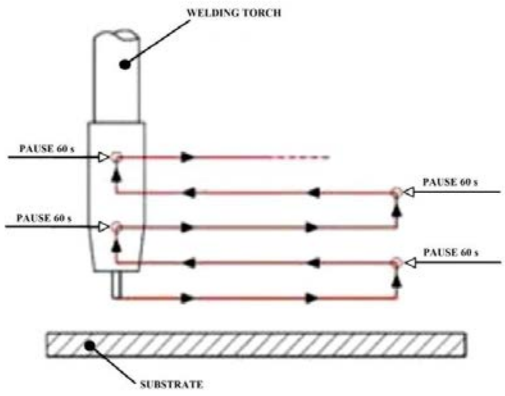
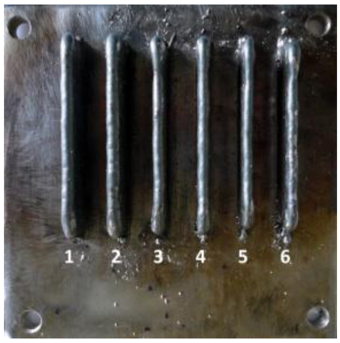
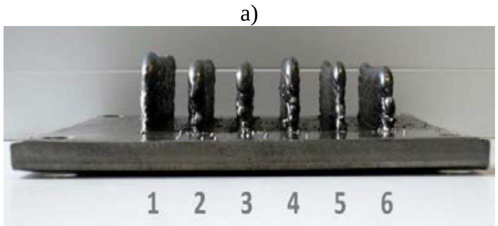


Fig. 1 - Strategy of deposition of the layers. The 60s pause is highlighted.



a)



b)

Fig. 2 - Nesting of the samples on the substrate

Tab. 1 - Process parameters of the welding process relative to each sample

Sample	Current [A]	Voltage [V]	Wire Speed [m/min]	Speed Rate [mm/min]	Heat Input [J/m]
1	50	11,7	1,68	300	11707
2	50	13,1	1,68	300	13084
3	50	13,1	1,68	375	10467
4	50	11,7	1,68	375	9365
5	50	11,7	1,68	450	7805
6	50	13,1	1,68	450	8723

3. Results

In the hereinafter the microstructures of the different samples will be discussed. In all the samples three different zones can be observed: the lower zone, the middle zone, the upper zone. The lower zones is characterized by being in contact with the cold substrate before the deposition, the middle zone is characterized by the lower thermal shock, since the substrate of that zone is a warm weld bead

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