THE EFFECT OF SHIELDING GAS ON SELECTED GEOMETRIC CHARACTERISTICS OF MULTILAYER WALLS PRODUCED BY WAAM

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Abstract

The research deals with the comparison of the influence of two different shielding gases (argon and gas mixture Inoxline He30H2C) during Wire Arc Additive Manufacturing (WAAM) using CMT mode process. The influence on geometric characteristics of multilayer walls (surface waviness, component height, effective and total wall thickness) was researched. A thin-walled component consisting of 53 overlay beads was designed to compare the effect of two different shielding gases on the geometric characteristics of multilayer Inconel 718 alloy component. During the overlay welding process, electrical process parameters were monitored using the HKS WeldAnalyst - S3 measuring device. The geometrical characteristics of the multilayer overlay weld walls were evaluated by optical 3D scanning on the GOM ATOS II TripleScan device. The obtained data were statistically processed in Prism GraphPad software. The results confirmed statistical significance between shielding gases in terms of component height as well as total and effective wall thickness. From surface waviness evaluation point of view, the statistical significance between the shielding gases was not confirmed.

Keywords: CMT, argon, Inoxline He30H2C, HKS WeldAnalyst, statistical evaluation

1. Introduction

Additive manufacturing is experiencing its rise due to the ability to produce complex three-dimensional components with great geometric accuracy, thereby reducing the amount of materials compared to conventional manufacturing technologies. Additive processes using laser or electron beam as heat sources are mainly used to melt metal powder. In these manufacturing processes, parts achieve accurate dimensions, but the deposition rate is low, which increases production time. Furthermore, metal powder makes the process itself more vulnerable to defects such as pores, especially at dynamic loading, which affect the structural integrity of components [1]. On the other hand, the principle of WAAM technology is to deposit several layers of material on top of each other and next to each other until the part is created. An electric arc is used to melt welding wire, which is used as filler material. The disadvantage of the technology is a lower geometric accuracy than when using metal powders, but due to a higher deposition speed, a production of large components in a shorter time is achieved [2]. There are few other advantages compared to conventional additive manufacturing: a wide range of additive materials, lower initial costs, the ability to produce components composed of multiple materials, and higher mechanical properties compared to casting and forming technology [3, 4].

To apply WAAM technology, it's crucial that the mechanical and geometric properties of the deposited parts are in accordance with the necessary requirements. Specifically, with regards to geometry, this means ensuring that the deposited component meets the required height, width, and surface waviness as specified [5]. The surface waviness of the component can be defined as the difference between the absolute and effective wall width. It can reach a value of up to 0.5 mm and acts as a concentrator of geometric stresses, thus limiting the applicability of WAAM components immediately after their production under dynamic load conditions. The waviness must be therefore removed after deposition so, that the component is rid of geometric irregularities and is flat along its entire length [6]. To compete with other technologies, it is necessary to reduce the costs of deposit processing, which can be achieved by choosing a set of process parameters that produces the minimum residual material [7].

Several authors dealt with the influence of process parameters and cooling strategy. Spencer et al. found that by reducing the interpass temperature, the surface waviness also decreases, which is, however, related to reduced productivity due to longer cooling times [8]. Kazanas et al. claim that by applying a smaller heat input using the CMT mode, it is possible to achieve a more uniform profile of the welding bead and therefore lower surface waviness values of the manufactured component [9]. Another important factor affecting the mechanical properties of the component is the choice of shielding gas. Jurić et al. monitored the influence of 4 types of gas in MAG-WAAM on the surface waviness of components:

- Inoxline C2 (97.5 % Ar, 2.5 % CO_2),
- Inoxline He3 H1 (95.5 % Ar, 3 % He, 1.5 % H_2),
- Inoxline H5 (95 % Ar, 5 % H_2),
- Argon 5.0 (99.999 % Ar).

They found that the component made with the Inoxline C2 shielding atmosphere showed the highest values of surface waviness. The authors assumed that the cause may be an admixture of carbon dioxide in the protective gas that contains oxygen. On the contrary, the overlay weld with Inoxline H5 shielding gas (95% Ar, 5% H_2) achieved the smallest waviness [10]. Similar results were obtained in research by Gurcik et al., who investigated the effect of individual components of the shielding gas on the resulting geometry of the deposit. The authors found that as the amount of CO_2 and helium increases, the waviness of the deposit also increases. According to the authors, the cause is the high thermal conductivity of these gases [11]. Yamaguchi et al. investigated the influence of Ar and CO_2 gases on the surface roughness of the deposited components. The authors found that by applying a higher heat input surface, higher values of surface roughness are achieved. The Ar gas enables a lower surface roughness of the thin-wall structure than the CO_2 gas [12]. Therefore, the aim of the experiment was a detailed analysis of the effect of the gas type choice on the height, width and surface waviness of multilayer linear walls produced in the CMT mode and the analysis of the suitability of these gases to produce components with the required geometry and surface waviness.

2. Materials and methods

The walls were deposited to the S235 carbon steel base material. The substrate in WAAM is usually made of a cheaper material, as it is removed after the deposition. WAAM is effective in the production of large components from more expensive alloys because it has a low buy-to-fly (BTF) ratio. It is the ratio between the input material for production and the finished component, which is significantly lower compared to conventional machining [13]. Therefore, the corrosion-resistant nickel alloy Inconel 718 in the form of NiCro 718 MIG wire with a diameter of 1.2 mm was used as a filler material. Table 1 shows the chemical composition of the welding wire.

Table 1. Chemical composition of NiCro 718 wire in wt. % according to manufacturer

C	Mn	Si	S	P	Cr	Ni	Mo
0.07	0.1	0.15	0.001	0.008	17.5	52	3
Al	**Ti**	**Co**	**Cu**	**Nb + Ta**	**B**	**Fe**	
0.4	0.9	0.05	0.05	5	0.005	Balance	

For a precise analysis of the influence of the gas option on the resulting geometry, the 99.996 % pure Argon and Inoxline He30H2C gases were used. Chemical composition of the Inoxline gas is provided in Table 2.

Table 2. Composition of shielding gas Inoxline He30H2C

Chemical composition [%]	
Argon	67.88
Helium	30
Hydrogen	2
Carbon dioxide	0.12

Using each gas, walls were deposited by applying the interpass temperature of 100 °C. Each wall consisted of 53 layers. A Fronius TPS 600i power source was used to deposit the walls.
The length of the walls was 150 mm. HKS WeldAnalyst system was used to determine the RMS (root mean square) values of deposition current and voltage. The measured values of the process parameters and the calculated values of the heat input are shown in Table 3.

Table 3. Process parameters for WAAM deposition

Process parameters	Gas	
	Argon	Inoxline
RMS current value [A]	209.61	206.03
RMS voltage value [V]	13.66	15.33
Deposition speed [mm/s]	5	5
Wire feed rate [m/min]	8	8
Shield gas flow rate [l/min]	15	15
Heat input [J/mm]	527.65	639.92

The geometric characteristics of the walls were analysed using the GOM ATOS II TripleScan 3D scanner. Due to slight fluctuations in the geometry of the deposits, 11 virtual sections were created on each wall (Figure 1), and then the height and width values of each component were measured, and finally the surface waviness values were calculated.

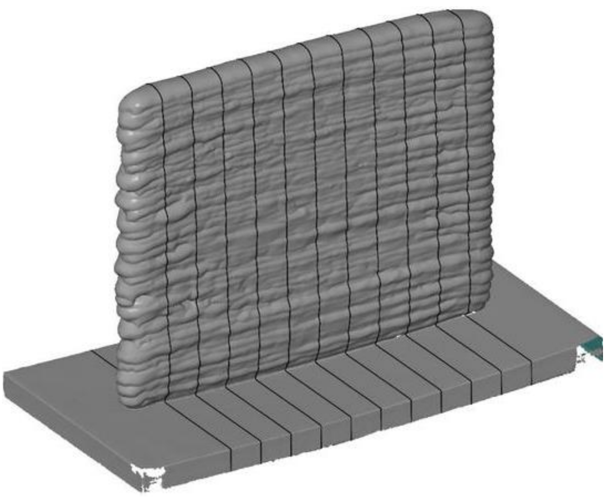

Figure 1. Positions of virtual cross sections

The waviness was determined by plotting line segments that intersected deposits at its narrowest and widest points. The distance between the line segments is the surface waviness value. The principle of surface waviness measurement is shown in Figure 2.

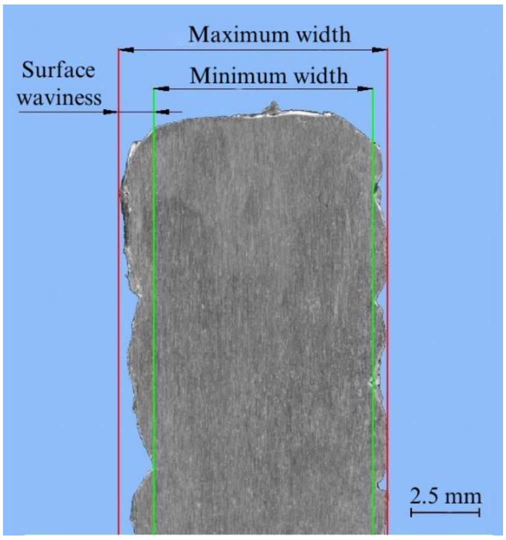

Figure 2. Waviness measurement principle

The data obtained from scans were evaluated using the GraphPad Prism 8 statistical software.

3. Results and discussion

Figures 3 and 4 show components that are overlayed in two different protective gases using the interpass temperature. The components show uneven surfaces, which is typical for WAAM technology, as well as curvature of the substrate, which is caused by high stress resulting from the high heat input and its accumulation.

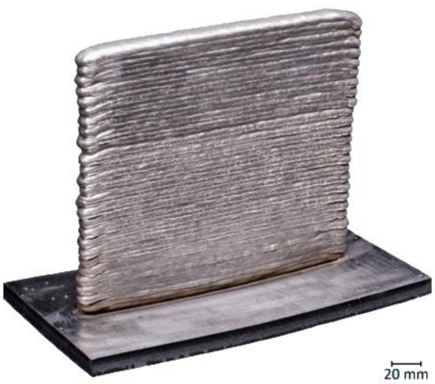

Figure 3. CMT multilayer component made in Inoxline protective atmosphere

Figure 4. CMT multilayer component made in Argon protective atmosphere

Tables 4 provides the measured values of the geometric characteristics of the deposits made in Argon and Inoxline protective gases using interpass temperature.

Table 4 Dependence of component geometric characteristics on the protective gas option in CMT mode

CMT	Inoxline	Argon
Maximum width [mm]	14.91	13.22
Minimum width [mm]	9.74	7.97
Surface waviness [mm]	2.68	2.81
Minimum height [mm]	138.52	143.42

As can be seen in the Table 4, the deposit made in the protective Inoxline atmosphere reached a maximum width of 12.8 % higher compared to component made in the argon gas. This component would also be 22.2 % wider after milling process. With regard to surface waviness, component made in protective argon atmospere reached 4.9 % greater values compared to component made in Inoxline gas. This deposit was also higher by 3.5 %. The larger width and smaller height of the component made in the protective atmosphere of Inoxline gas can be explained by the larger content of the helium, which has a greater ionization potential. The electric arc reaches a higher temperature, the molten metal has a greater wettability, and during deposition, spreads more to the sides, which increases the width of the component at the expense of its height. All values related to the geometry of the overlay weld walls showed a normal distribution. T-test statistical analysis confirmed the significance between particular protective atmospheres in terms of the maximum and minimum width as well as height of the components (Figures 5, 6, 7). On the other hand, statistical significance regarding components surface waviness was not confirmed.

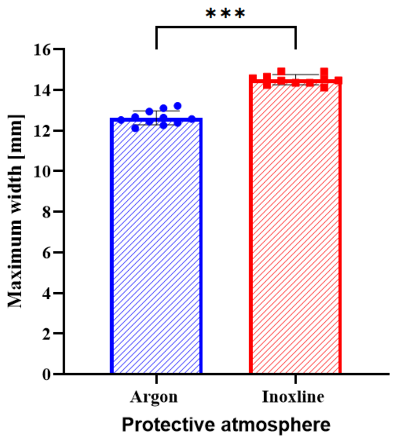

Figure 5 T-test of the maximum width of the component with respect to the protective atmosphere; *** $p \leq 0.001$

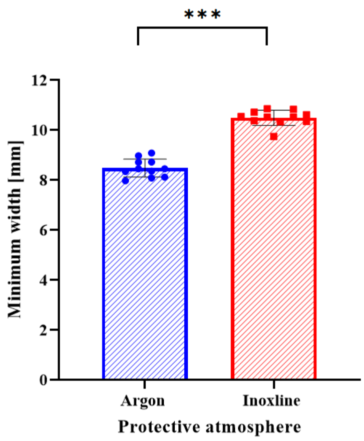

Figure 6 T-test of the minimum width of the component with respect to the protective atmosphere; *** $p \leq 0.001$

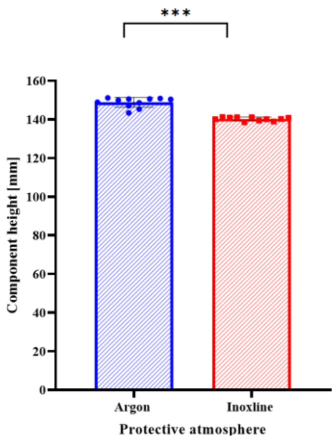

Figure 7 T-test of the component height of the component with respect to the protective atmosphere; *** $p \leq 0.001$

Figure 8 shows the dependence of the minimum height, width, and surface waviness of the deposit on the heat input and the gas protective atmosphere. The heat input depends on the selected deposition mode, the effective deposition current, the voltage values, and the deposition speed. As the heat input increased, the width of the component grew. On the contrary, with its increase, the height decreased linearly.

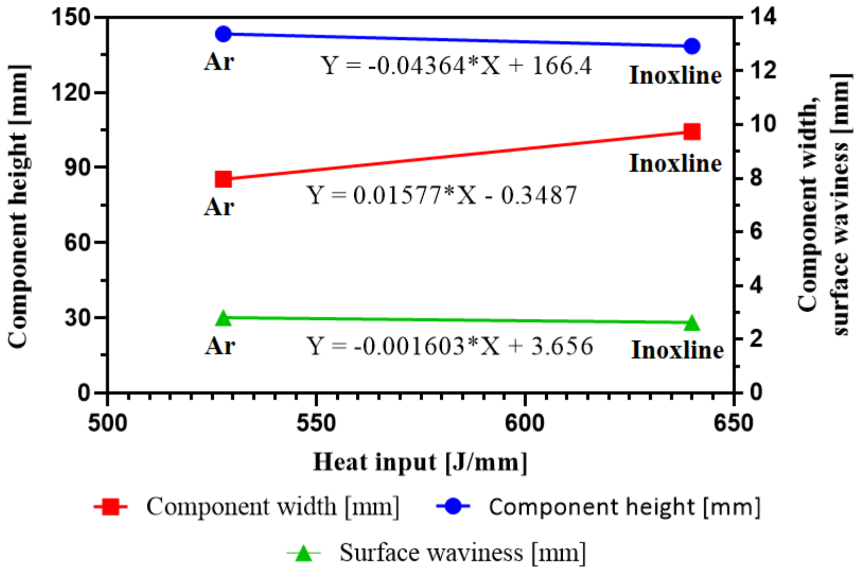

Figure 8 The effect of heat input and protective gas on geometric characteristics of the overlay weld wall

5. Conclusions

In the experiment, the influence of the application of different protective gases (argon, Inoxline) on the resulting geometry of components made by overlay welding Inconel 718 using WAAM technology was observed. Based on the analysis of the experimental data, the following conclusions can be drawn.

1. Using the argon protective gas, the heat input decreased by 17.54 % in comparison to Inoxline protective gas.
2. Applying a lower heat input in the case of the deposition in argon protective gas, the wall thickness decreases, and the height of the component increases. On the contrary, Inoxline protective gas increases the width of the overlay weld wall at the expense of its height.
3. In the case of deposition in the Inoxline protective gas, the overlay weld wall was characterized by smaller surface waviness, but the statistical analysis by T-test did not confirm the effect of gas selection on this charakteristic.
4. Applying Inoxline atmosphere, the component reached a maximum width of 12.8 % higher compared to component made in the protection of the argon and was also lower by 3.5 %. This component would also be 22.2 % wider after milling process.

6. Acknowledgements

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7. References

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