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THE USE OF A MICROCONTROLLER FOR LEVEL CONTROL IN A SUBMERGED COOLING SYSTEM APPLIED TO WIRE ARC ADDITIVE MANUFACTURING

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Abstract. *Additive Manufacturing (AM) is a manufacturing technique that offers numerous advantages over traditional methods, including the ability to produce complex parts with high precision and quality while reducing production time and cost. In the case of metallic parts, Wire Arc Additive Manufacturing (WAAM) stands out. WAAM is a complex process involving multiple variables that influence the finish quality, as well as the mechanical and metallurgical properties of the manufactured part. Proper temperature control during the WAAM process can reduce the occurrence of deformations, cracks, and porosities, thereby improving surface quality and mechanical strength. Implementing a microcontroller system for liquid level control in a submerged cooling process is beneficial for WAAM, as it allows for process improvement and optimization, reducing material waste and increasing productivity. Precise control of the liquid level ensures effective cooling. This work aims to develop a microcontroller system for liquid level control in the submerged cooling process applied to WAAM, enabling part production optimization and temperature control. The developed system prototype comprises a liquid-level sensor, microcontroller, and actuator that regulates liquid flow in the cooling process. Preliminary results demonstrate the efficacy of the developed prototype in the WAAM process, yielding metallic forms with appreciable finishing and speed.*

Keywords: *Waam, Cooling system, Submersion, Microcontrollers, Sensors.*

1. INTRODUCTION

Additive Manufacturing (AM), also known as 3D printing, as addressed by Araújo and Cavalcante (2021), has revolutionized the manufacturing industry, offering an innovative and flexible approach to producing complex and customized parts. This technology enables the creation of three-dimensional objects layer by layer using various materials such as polymers, metals, and ceramics. Among the AM processes for metal parts manufacturing, the Wire Arc Additive Manufacturing (WAAM) technology stands out, which utilizes an electric arc to melt and deposit metal wire with high productivity (Silva and Sousa, 2020). Studies by Huang, Leu, and Mazumder (2015) and Martins, Rodriguez, Williams, and Pinkerton (2018) have explored Additive Manufacturing of metals, analyzing its characteristics, challenges, and potential industrial applications.

WAAM is an innovative manufacturing process that allows for the direct production of complex and customized metal parts. However, the interpass temperature, i.e., the temperature of a layer during the period between the deposition of consecutive layers, that plays a crucial role in the quality and integrity of the manufactured parts. The interpass temperature directly influences different characteristics and properties of the parts, such as its microstructure, mechanical strength, presence of defects, and residual stresses. Therefore, understanding and properly controlling this variable are essential to ensure the quality and precision of the parts produced by WAAM.

With the aim of investigating the influence of interpass temperature in WAAM and developing effective thermal control strategies, several studies in recent years have focused on the microstructural evolution, performance enhancement, and failure mechanisms in parts produced by arc deposition, highlighting the importance of interpass temperature in controlling microstructure, mechanical properties, and residual stresses (Raghavan, Kamaraj, Arivazhagan,

and Sankaranarayanasamy, 2021; Harrysson, Cormier, and Marcellin-Little, 2014). As a solution for interpass temperature control and its effects, Carreira, Griffiths, and Pinkerton (2018) have explored the use of half-immersion systems and their impact on thermal control during WAAM. The half-immersion system applied in WAAM involves partial immersion of the part in a coolant liquid during the manufacturing process. This method aims to control temperature more effectively, avoiding distortions, improving the quality of the produced parts, and optimizing manufacturing time.

In this context, this work focuses on the development of a microcontroller-based cooling system with an emphasis on modular configurations, applying a half-immersion cooling technique in WAAM. This aims to enhance thermal control during the manufacturing process, offering flexibility to meet the diverse requirements and characteristics of the produced parts. The application's primary goal is to reduce interpass times, thereby reducing the overall production time.

2. MATERIALS AND METHODS

2.1 Experimental procedure

Validation of the microcontroller-based half-immersion cooling system is essential to ensure the quality of multilayer linear preforms. For this purpose, deposition experiments were carried out, with two preforms, both consisting of 10 layers, built using the specifications shown in Table 1 and subjected to different cooling conditions.

Table 1. Specifications.

Deposition process	GMAW
Wire	Carbon steel
Average current	50 A
Peak current	250 A
Wire feed speed	4 m/min
Displacement speed	300 mm/s
Shielding gas	Argon 75% / Helium 25%
Interpass temperature	80 °C

2.2 Active cooling system using the half-immersion technique

Figure 1 presents the schematic diagram of the developed system, composed of various components. The system consists of a tank (E) that encompasses the working area of the deposition torch (C), from where the material deposition process onto the substrate (D) takes place. The liquid contained in the reservoir (A) is introduced into the system through a pump (B) and directed to the reservoir (F) by gravity. The liquid circulates continuously within the tank (E), with the inlet and outlet located at the ends. The control of the tank level is achieved by controlling the water inflow through the pump during the layer deposition process.

The operation of the microcontroller system is depicted in the flowchart in Figure 2, illustrating the work algorithm and operational steps. The algorithm is responsible for controlling the various aspects of the system, ensuring the proper flow of the liquid in addition to monitoring and adjusting the tank level.
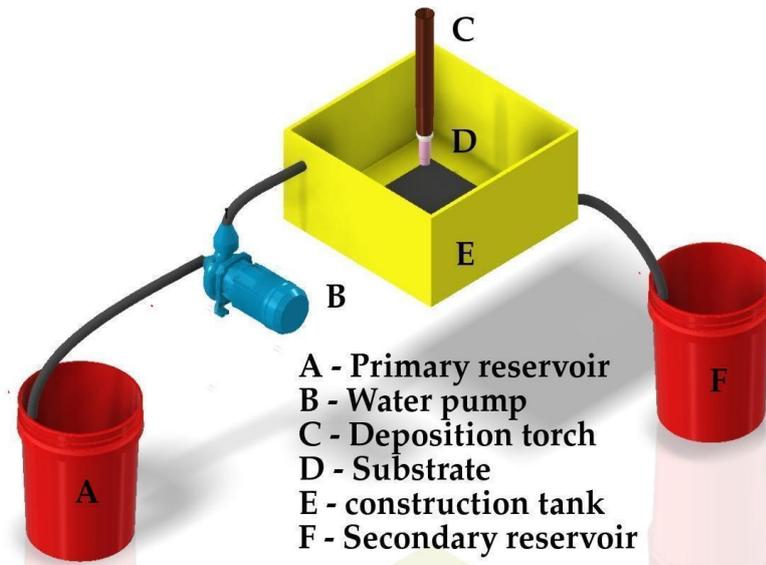
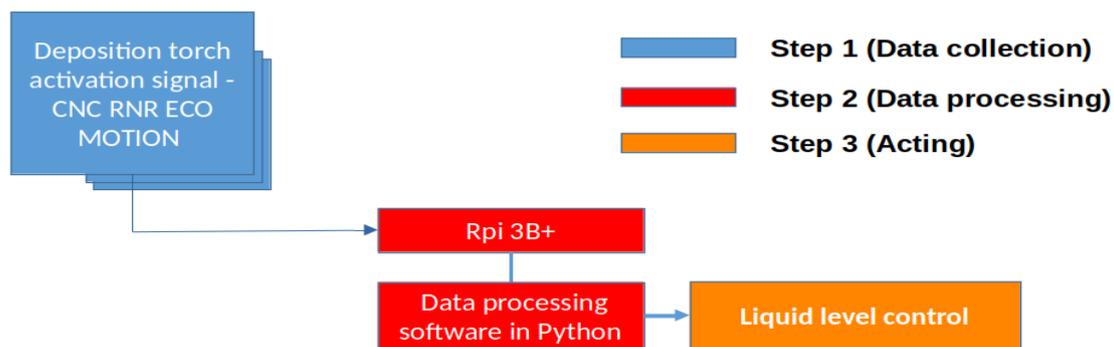Figure 1. Schematic diagram of the half-immersion cooling system.

Figure 2. Algorithm of operation for the microcontroller system.

2.3 Microcontroller system

The Raspberry Pi 3 B+ (Rpi3B+) was used as the base platform, which has a fully compatible operating system with Python 3, which allows you to take advantage of its high-level programming. The Python algorithm runs in an infinite loop throughout the entire part construction process, as illustrated in Figure 2. Within this loop, the algorithm can be divided into three distinct stages.

In the first stage, data from the task execution is collected. In this case, the only data collected is the activation pulse of the deposition torch. When the system detects a high level coming from the activation pin of the torch, directly from the CNC controller (Figure 3), it recognizes that the machine is depositing material. Then, when a low level is detected, the system knows that a layer of material has been deposited and the part is higher.

In the second stage, the system calculates the equivalent height of the part, taking into account an additional constant that represents the height of the deposited layer.

In the third stage, the system increments the signal of the triac in the electronic circuit, as shown in Figure 4. This results in an increase in the speed of the water pump, increasing the water flow and consequently raising the water level in the cooling tank. The system increments the triac signal with each deposition.
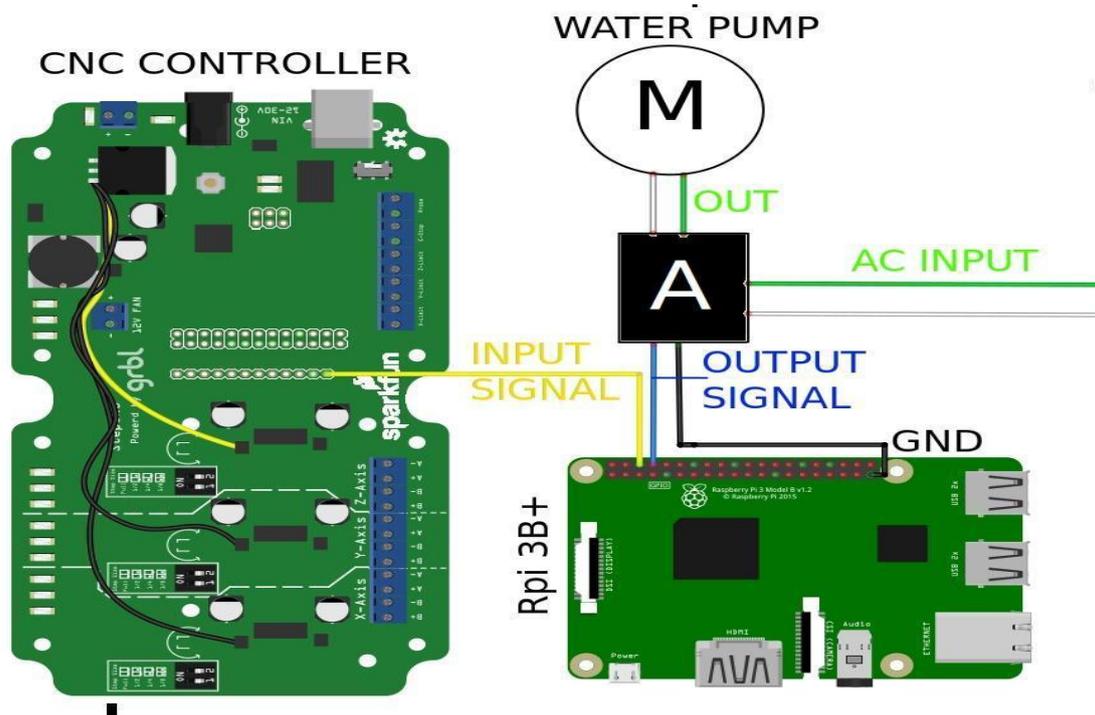
Figure 3. Assembly of the control components of the cooling system.

It was essential to apply circuit A presented in Figure 4 to control the water pump, as its motor is of the AC type, as indicated in Figure 3.
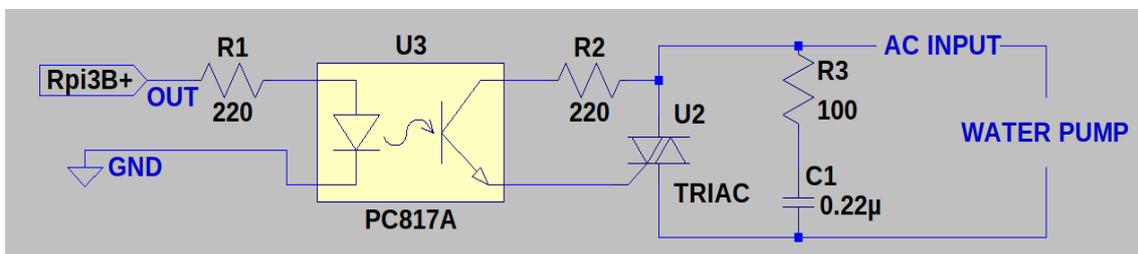

Figure 4. Electronic circuit of block 'A'.

3. RESULTS AND DISCUSSIONS

3.1. Geometric analysis

Figure 5 and Figure 6 depict the two preforms produced in their respective manufacturing setups.

Figure 5. (A) Preform 1, built under passive cooling; (B) Setup 1, used for the preform construction.

Figure 6. (A) Preform 2, built under active cooling; (B) Setup 2 used for the preform construction.

Figure 7 and Figure 8 present the manufactured preforms, including their height and useful width dimensions on their cross-section views.
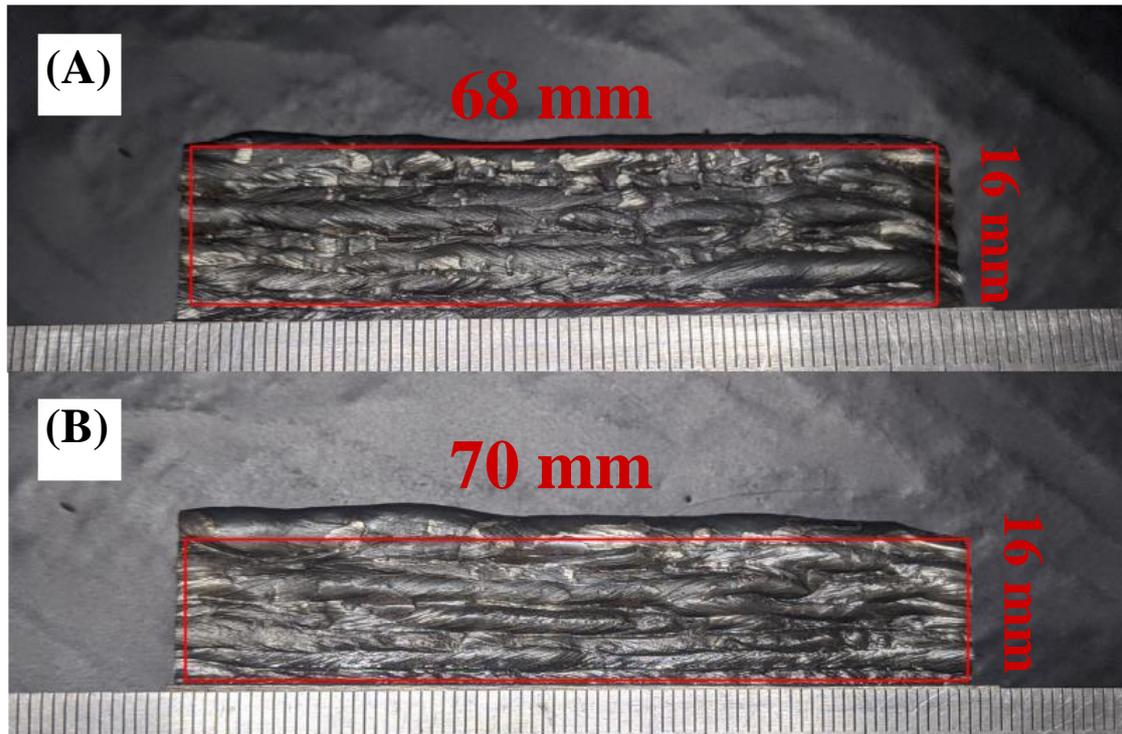
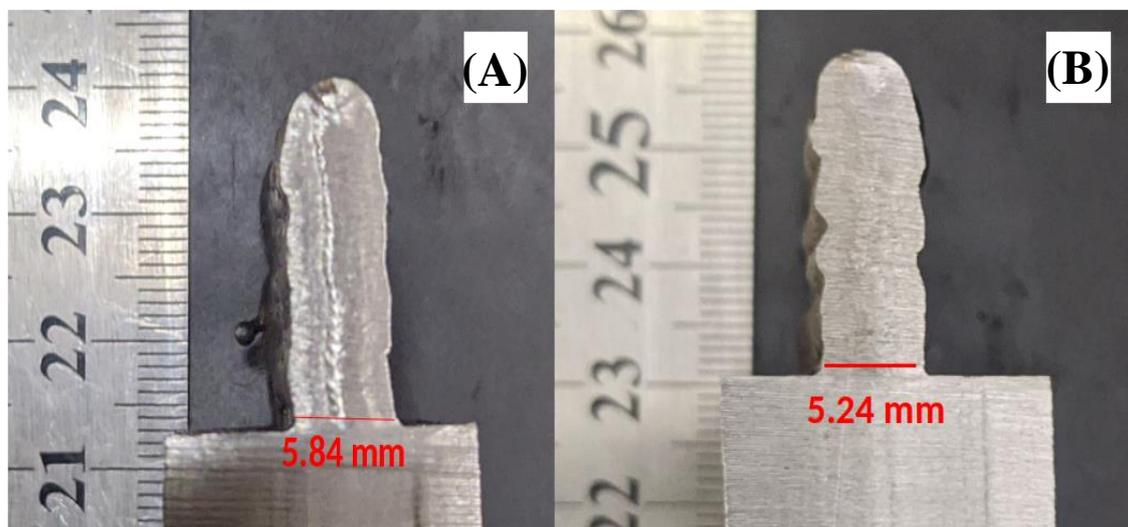Figure 7. (A) Dimensions of preform 1; (B) Dimensions of preform 2.

Figure 8. (A) Dimensions of the central cross-section of preform 1; (B) Dimensions of the central cross-section of preform 2.

From the lateral view, it can be observed that the preform subjected to the cooling system (preform 2) exhibited a comparable, albeit slightly higher, useful area, with a 0.03% increase compared to the preform produced under passive cooling (preform 1). This difference is significant and demonstrates the efficiency of the cooling system in maintaining the useful area of the preform, replicating the results obtained by Silva et al. (2018).

As for the central cross-section view, as shown in Figure 8, preform 1 achieved a 0.1% larger useful area compared to preform 2.

The discrepancies in the dimensions of the functional areas and the roughness between preform 1 and preform 2 arise due to the more effective control of heat accumulation by the cooling system during the deposition process, resulting in less expansion of the workpiece (Felice, Oliveira, 2020).

3.2. Analysis of the time to reach the interpass temperature

Figure 9 and Table 2 present an analysis of the interpass times from the torch shutdown until the desired interpass temperature is reached after the deposition of the final layer, as indicated in Table 1.
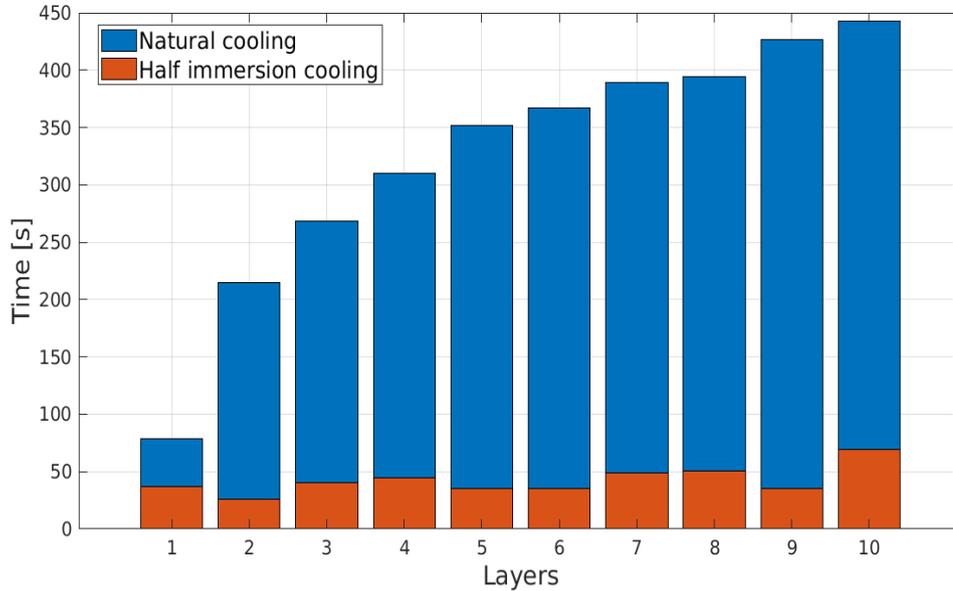

Figure 9. Waiting times until reaching the interpass temperature of 80°C.

Table 2. Comparison of interpass time (s) between natural and half immersion cooling systems.

	Time to reach intermediate temperature [s]	
Layers	Natural cooling	Half immersion cooling
1	79	37
2	215	26
3	268	40
4	310	45
5	352	35
6	367	35
7	389	49
8	394	51
9	427	35
10	443	69

The results demonstrated that the use of the half-immersion water cooling system was highly efficient, with a reduction of up to 92% in interpass time and 87% in total manufacturing time compared to the natural cooling method used in preform 1. This observation reinforces the importance of choosing appropriate and efficient cooling techniques to minimize interpass time during the layer deposition process, improve overall process efficiency, and increase

productivity. These results contribute significantly to the research field of materials processing, providing greater technical knowledge for the development of more advanced technologies and more efficient processes.

3. CONCLUSIONS

After investigating the effects of active near-immersion cooling on thermal management during wire arc additive manufacturing (WAAM), it is observed that this approach has had a significant impact. By utilizing the cooling system, the total active preform manufacturing time was reduced by 87%, indicating a substantial increase in process productivity. Additionally, it was determined that the useful area of the side section of the preform increased by 0.03%, while the central section decreased by only 0.1% compared to the preform manufactured with natural cooling. These results signify that this cooling system is highly effective in enhancing WAAM process productivity without compromising the preform's useful dimensions and surface quality.

4. ACKNOWLEDGMENTS

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