Thermal and Electrical Profiling of Wire Arc Additive Manufacturing (WAAM) Processes

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Motivation

In Gas Metal Arc Welding (GMAW), the weld bead geometry is different at the start and end of the arc compared to the middle. When attempting to create a simple wall-like structure by doing multiple weld passes, the upper layers can start to diverge from the intended design. Due to heat differences accumulating in each layer, sagging at the ends of the wall, for example, can occur. This is not ideal for additive manufacturing, as it requires the material to be distributed evenly and not vary in each layer. We studied this phenomenon by welding a wall and measuring the properties at each layer with a thermal camera and DAQ.

Goal: This is the first step of a broader project of WAAM optimization based on current and voltage control with GMAW.

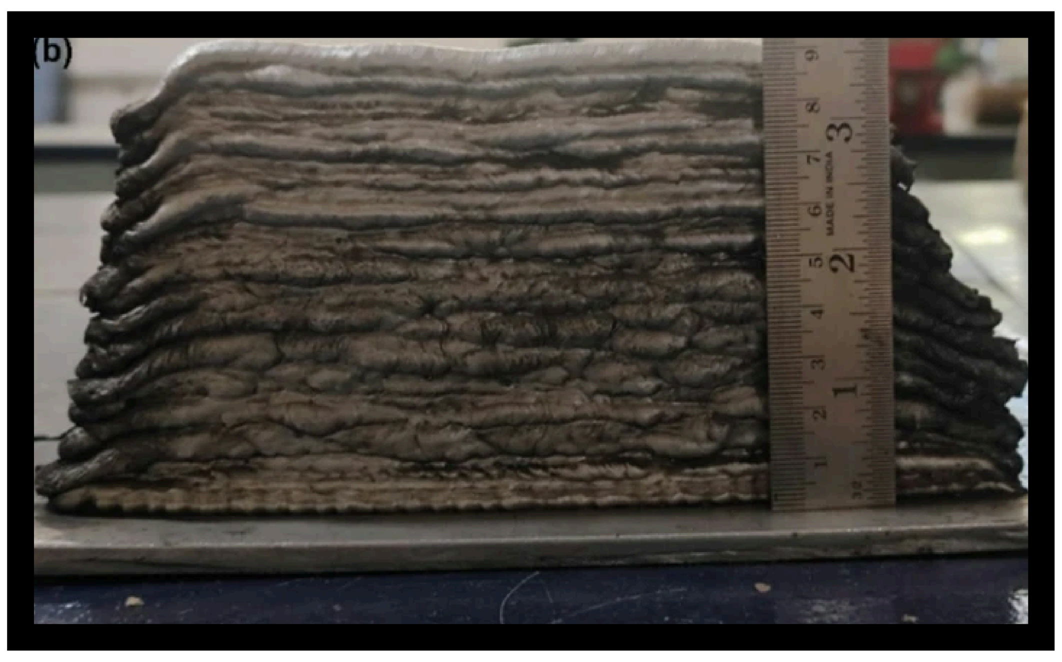

Figure 1: First Attempts of Wire-Arc Additively Manufactured Wall with sagging at edges due to heat variability in layers. Image source Sathishkumar, M., 2026

Background

Why Additive Manufacturing (AM)?

- Cost effectiveness due to its minimal material waste and rapid prototyping.
- Metal additive manufacturing can be done through a variety of welding tecniques. It has become prevalent in the aerospace and construction industries.

Why GMAW?

- GMAW is typically a very cost effective welding technique for large, less intricate prints. It does not require expensive metal powders or laser equipment and instead uses a cheap wire feedstock.
- Though it is less precise, GMAW can be faster to finish products due to its high deposition rate.

Wire Arc Additive Manufacturing (WAAM) combines the convenience and cost effectiveness of both additive manufacturing and GMAW welding make for an attractive manufacturing option for any industry.

Method

Weld parameters:

- **Pulsed-current rapid arc GMAW (synergic mode)**
- WFS: 135 in/min
- Travel speed: 15.75 in/min
- CTWD: 0.7 in
- Gas flow: 35 CFH
- Gas composition: Ar CO2 StarGold C-15

Wall properties:

- 1-bead thick, no weave
- ER70S-6 steel wire, 1.2mm in diameter.
- Steel baseplate of thickness 1 inch

To compensate for shrinking, the layer height increment was manually adjusted down every ~10 layers. No cooling techniques were used.

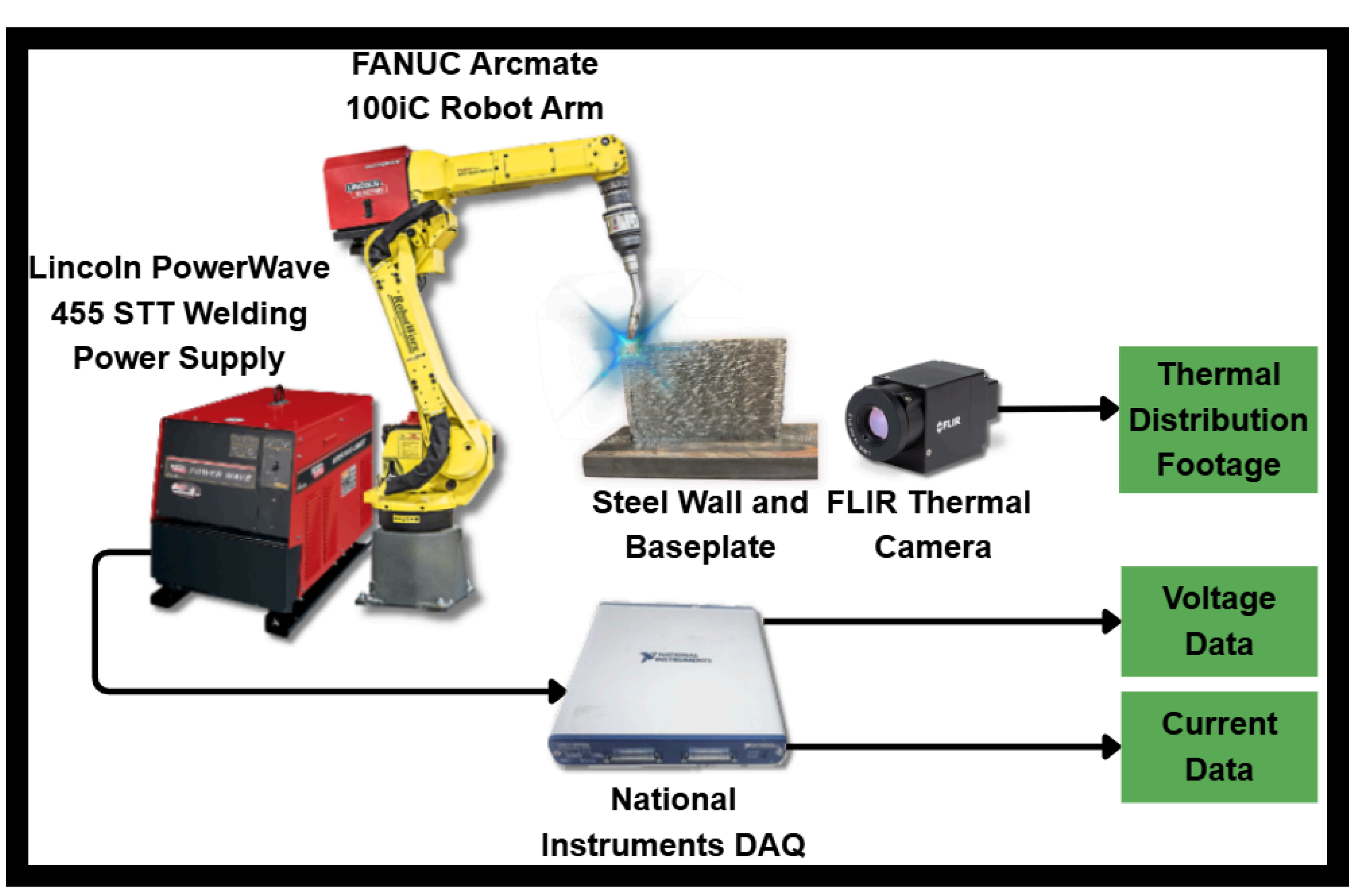

Figure 2: Experimental Setup and Output Data

Results

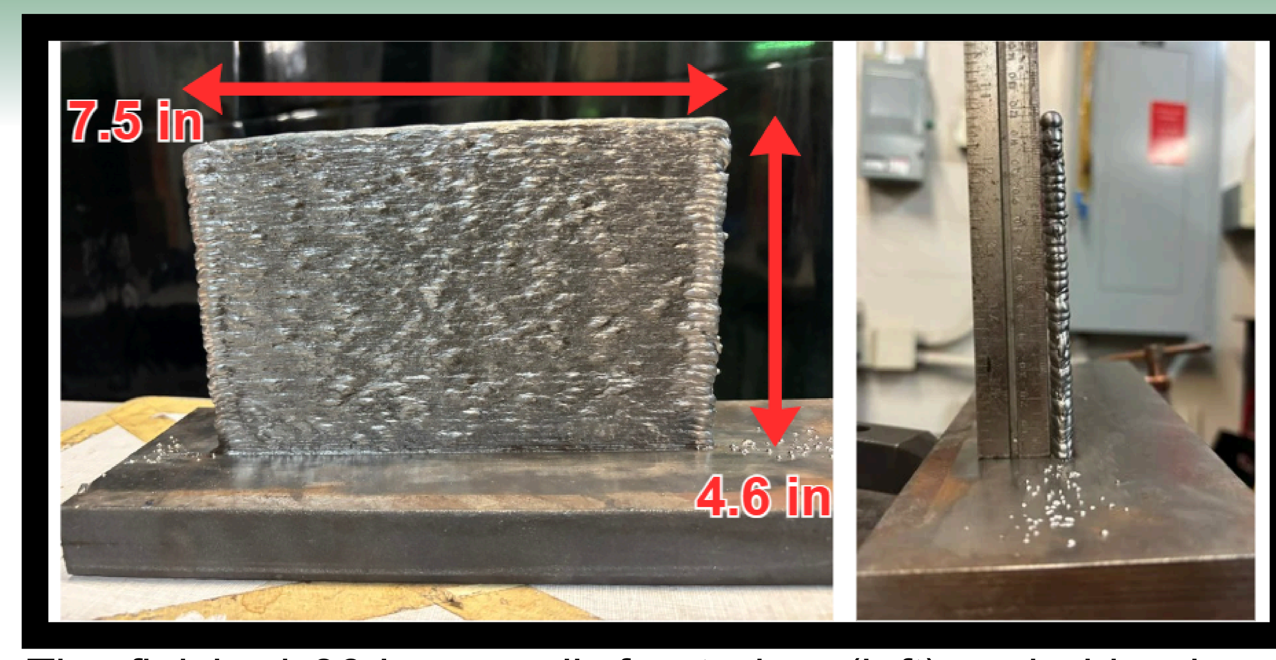

Figure 3: The finished 86-layer wall, front view (left) and side view (right). It is approximately 7.5 wide, 4.6 inches tall, and 1/4 inch thick and built on a 1-inch thick steel base plate.

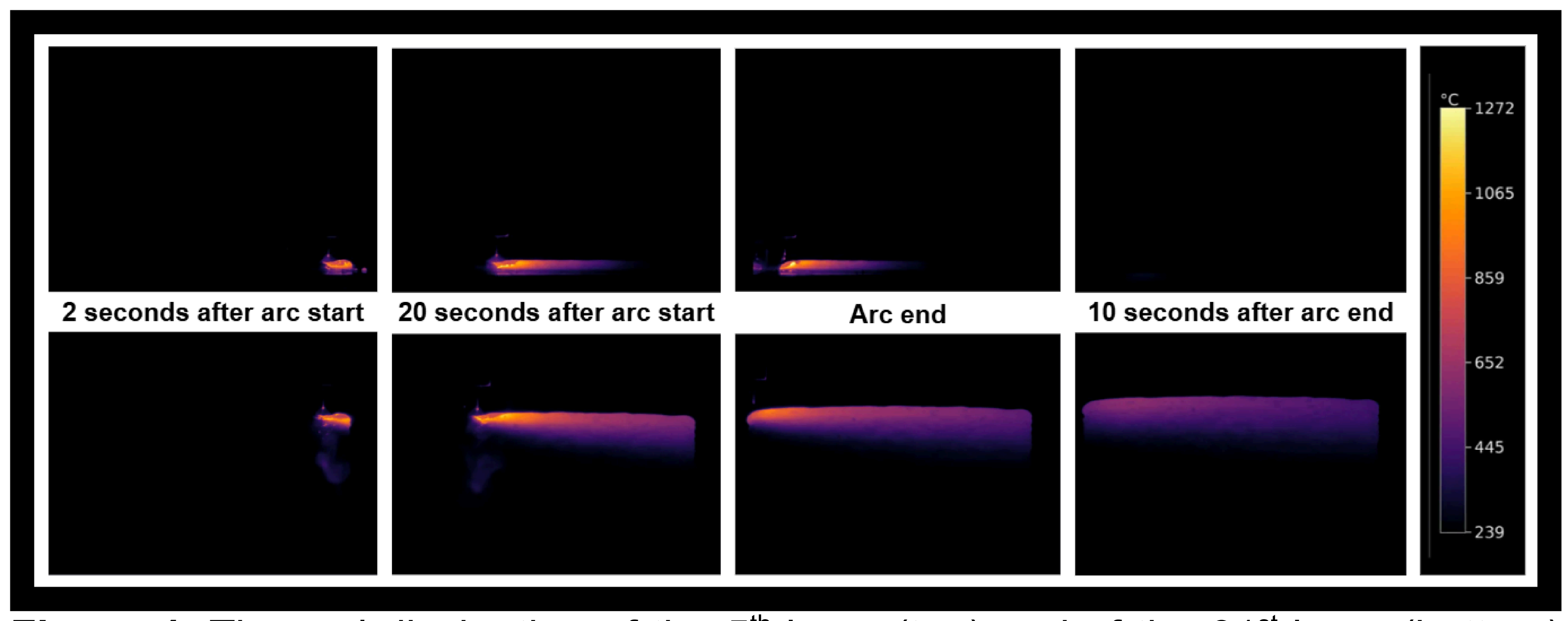

Figure 4: Thermal dissipation of the 5th layer (top) and of the 81st layer (bottom) over time

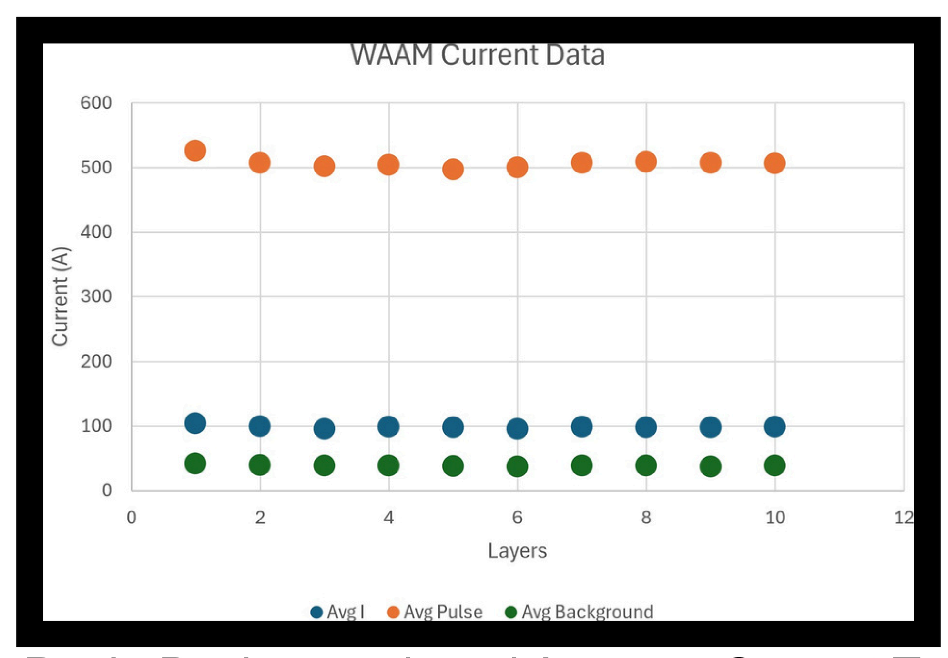

Figure 5: Average Peak, Background, and Average Current Trends by Layer

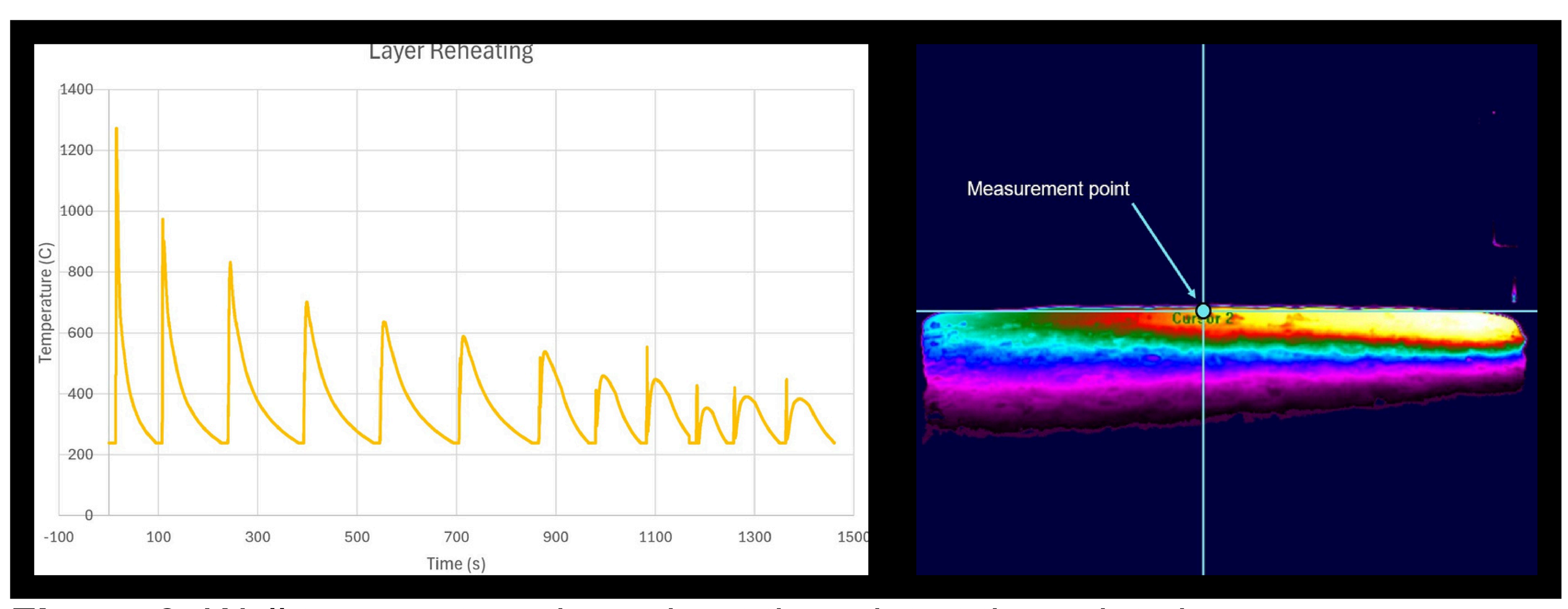

Figure 6: Wall temperature throughout the print at the point shown

Discussion

It has been consistently difficult to build perfectly square walls only by stacking weld beads. Warping at the ends from heat differences and bead geometry variation in each layer is quite common, so we were surprised at how square our wall was on our first attempt with the FANUC robot arm. As expected, the average current stays somewhat constant and heat dissipation time generally increases with more layers. We hope that in sharing the data we collected we can further advance WAAM technology with the help of interested researchers and professionals.

Conclusion

Our findings: Welding parameters and temperature profile of a GMAW square wall

Real world applicability: Optimizing a type of low-cost, high-speed manufacturing used in a wide variety of industries

Future Work: Analyse and simulate the collected data for further research in hopes to improve WAAM for other robots and/or alloys

Acknowledgments

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