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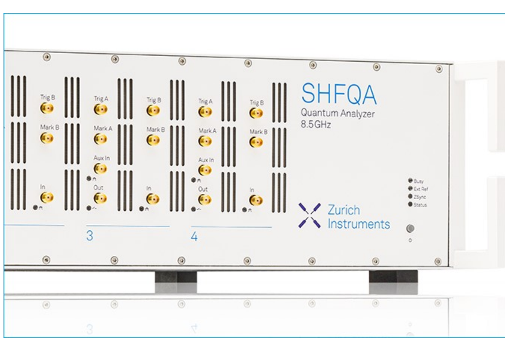

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Multi-Heat Input Technique for Aluminum WAAM Using DP-GMAW Process

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Abstract. Additive Manufacturing (AM) technologies are the future of production. To create parts with complicated dimensions under material saving constraints, AM process has an advantage over the traditional manufacturing processes. In this study, the Double Pulse Gas Metal Arc Welding (DP-GMAW) used to build-up the aluminum laminate wall based on the concept of the Wire and Arc Additive Manufacturing (WAAM). The GMAW robotic uses the aluminum filler wire ER5356 of diameter 1.2 millimeters as the additive material and aluminum 5083 as the substrate material. This additive process is shielded by industrial-grade argon gas. The present study research aims to improve the uniformity of the wall dimension by using the technique of multi-heat input/multi-condition proposed by this research. A technique used reduce the heat input during the build-up process. In this work, the build-up is performed on a closed figure path by laminating additive materials layer after layer. A total of 20 layers were performed with the double pulse welding parameters fixed to 5 Hz of frequency, 50 % of Duty cycle and Delta current set to 30 amperes. Moreover, each lamination was a constant of 1 millimeter in height. As for the multi-condition, it involves two techniques: (1) Reducing the welding current, and (2) Increasing the travel speed. The results indicated that the multi-heat input technique can improve the lamination dimension when compared to the fixed-heat input laminate wall. Furthermore, it was also found from the two techniques, the reducing of welding current technique produces more uniform laminate than increasing the travel speed technique. Therefore, it can be concluded that multi-heat input under the current reduction technique is the most appropriate approach to perform effective and uniform lamination layers.

INTRODUCTION

The Additive Manufacturing (AM) has developed the build-up process of producing or repairing metal parts of complex geometry while saving the cost of material. The AM is the official industry standard term (ASTM F2792) for all applications of the technology. It is defined as a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.

To build up material layers, thermal processes such as welding and laser melting processes are the most suited as they can effectively melt the material and consistently form layer upon layer [1-5].

The GMAW Process has high flexibility as it can create a uniform and good quality weld bead. In this process, many parameters could be altered to find the suitable match with the material being used to perform the additive process. In previous work, they focus on the to study in the Wire and Arc Additive Manufacturing (WAAM) process [1-4]. To develop the WAAM process procedure for the aluminum alloy, in this research had the advantage to conduct on aluminum alloys using the GMAW process.

To create the weld bead of large dimensions in term of width and height, Double-pulse (DP) current seems to be more effective with more uniformity compared to the traditional direct current (DC) as shown in Fig. 1 [5].

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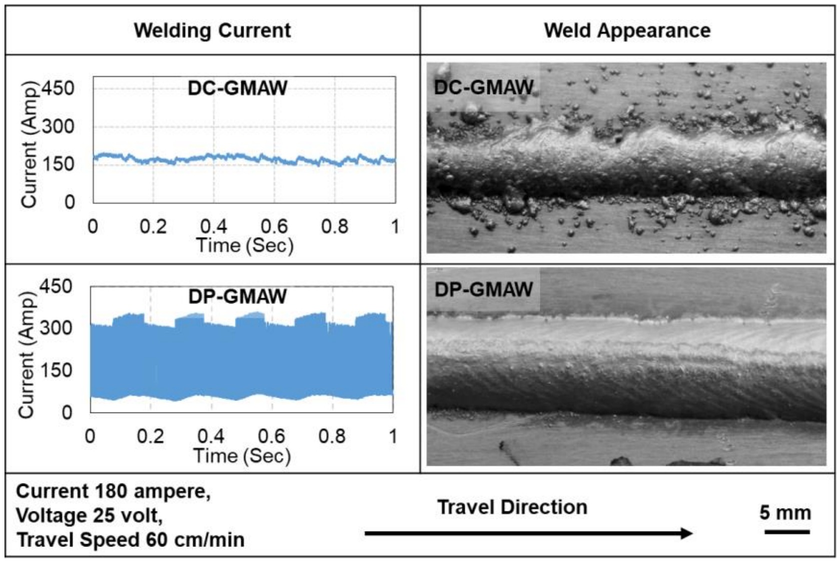


FIGURE 1. Double pulse current advantage on single bead appearance comparison.

This article aims to improve the dimension of the aluminum laminate using the multi-heat input or multi-condition in the build-up process. The two techniques were used in this study reducing the current and increasing the travel speed. The article's conclusion determines the effect of heat condition and shapes variation in order to develop the WAAM procedure.

EXPERIMENTAL SETUP

Experimental Procedure

Aluminum alloy wire ER5356 with a diameter of 1.2 millimeters was used as the build-up material, and industrial argon gas (99% pure) has been used to shield during the process. The argon gas used was about 15 liters per minute. The aluminum 5083 non-heat treatable grade with a thickness of 15 millimeters was used as a substrate material.

Regarding the GMAW process, the experimental set-up consisted of a double-pulse GMAW power supply of the OTC WB-P500L and welding robotic OTC FD-V8 was employed for controlling the precision and high repeatability of build-up path for the multi-layer experiment. Figure 2 shows the mapping setup of the experiment.

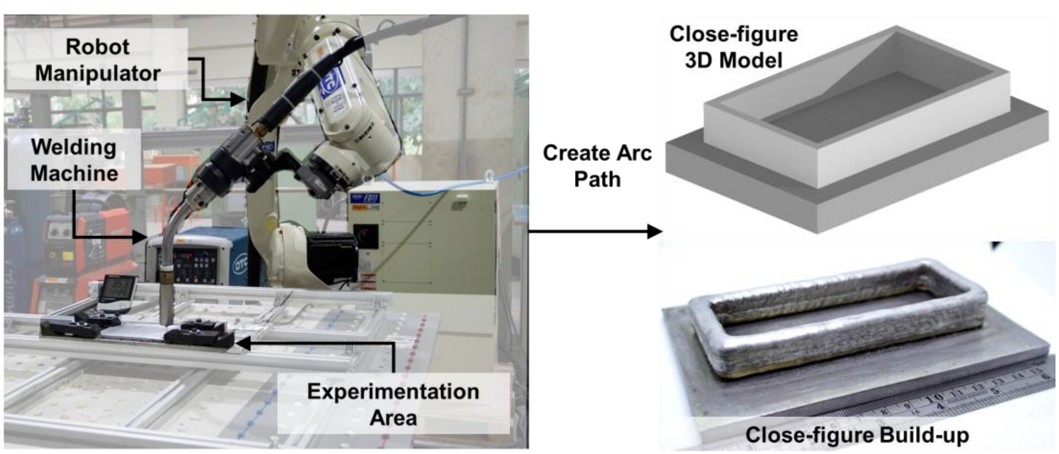


FIGURE 2. Experimental setups.

A laminated wall with close-figure path geometry was selected for this experiment where continuous weld layer upon layer was performed. The build-up Contact To Work Distance (CTWD) started from 15 millimeters and increased by 1-millimeter height with each layer. Previous studies found that significant effects on laminate dimension were due to welding current and travel speed [3]. Furthermore, the Taguchi experiment design was conducted to investigate the effect of heat conditions on the laminate feature. The heat input per layer Equation is used (Eq.1). Figure. 3 and Table 1 represent the schematic and experiment condition.

$$\text{Heat input per layer} = \sum_{i=1}^{\text{Total layer}} \frac{\text{Current}_i\ (\text{Amp}) \times \text{Voltage}_i\ (\text{Volt})}{\text{Travel Speed}_i\ (\text{mm/sec})} \times \frac{1}{\text{Total layer (n)}} \quad (1)$$

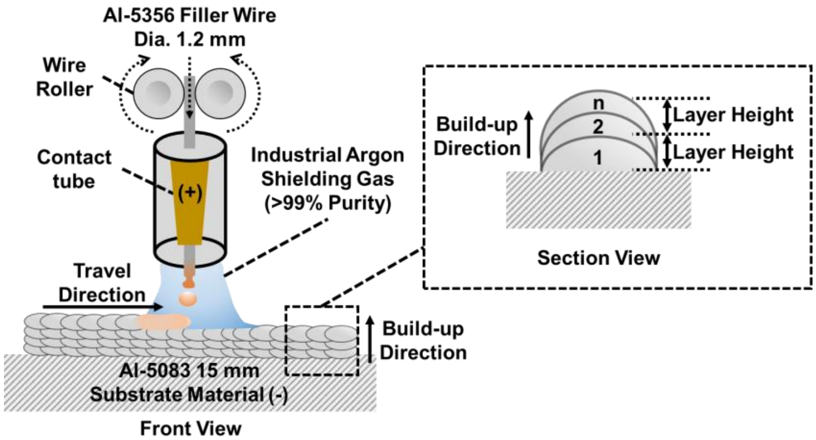


FIGURE 3. Schematic of the build-up experiment.

TABLE 1. Experimental condition.

Multi-layer Build-up Condition				
Condition	Single Condition	2 Multi Condition	4 Multi Condition	4 Multi Condition
Strategy Description	Fix Condition	Reduce Current	Reduce Current	Increase Travel Speed
Current (ampere)	120 (From layer 1 - 20)	120 (From layer 1 - 10) 90 (From layer 11 - 20)	120 (From layer 1 - 5) 90 (From layer 6 - 10) 67.5 (From layer 11- 15) 50.5 (From layer 16 - 20)	120 (From layer 1 - 20)
Wire Feed Speed (cm/min)	772 (From layer 1 - 20)	772 (From layer 1 - 10) 583 (From layer 11 - 20)	772 (From layer 1 - 5) 583 (From layer 6 - 10) 442 (From layer 11- 15) 335 (From layer 16 - 20)	772 (From layer 1 - 20)
Voltage (volt)	17.8 (From layer 1 - 20)	17.8 (From layer 1 - 10) 16.6 (From layer 11 - 20)	17.8 (From layer 1 - 5) 16.6 (From layer 6 - 10) 15.6 (From layer 11 - 15) 14.9 (From layer 16 - 20)	17.8 (From layer 1 - 20)
Travel Speed (cm/min)	120 (From layer 1 - 20)	120 (From layer 1 - 20)	120 (From layer 1 - 20)	120 (From layer 1 - 5) 150 (From layer 6 - 10) 188 (From layer 11 - 15) 234 (From layer 16 - 20)
Avg. Heat Input per layer (J/mm/layer)	106.8	90.75	67.94	78.81

Fixed Welding Parameters			
Frequency (Hz)	5	Shielding Gas Flow Rate (LPM)	15
Duty Cycle (%)	50	Layer Height (mm)	1
Delta Current (ampere)	30	Total Number Layer (n)	20

Metallurgical Procedure

The specimen was investigated on the cross-section of the middle length of the laminate wall. The specimen was grounded and polished. For etching, the aluminum additive specimen was used by Barker's reagent [6]

Macro Evaluation

To study the effect of heat condition on laminate wall dimension, the macro features were utilized which consist of:

1. Effective height: The minimum uniform height of the laminate layer.
2. Effective width: The minimum uniform width of the laminate layer.
3. Effective area (effective section area): The desirable area on the laminate layer.
4. Aspect ratio (height and width ratio): The desirable ratio of height and width to find the effective dimension of an individual specimen.

However, this article expects a greater height with a narrower width because an effective area needs to be larger with a high value of aspect ratio. Therefore, the height with a narrow dimension was used to build-up a part for fine detail [4]. In Fig. 4, the significant result of the laminate dimension is given. Moreover, the image processing was applied to measure each dimension precisely.

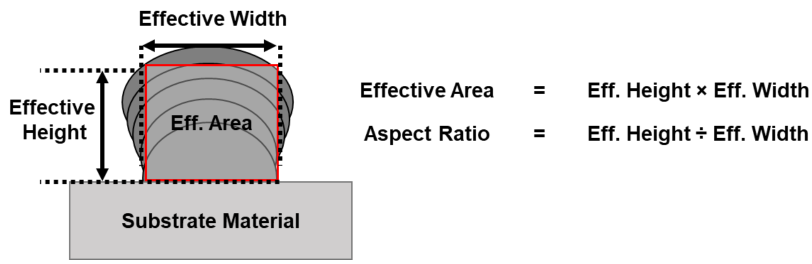


FIGURE 4. Macro feature dimension.

RESULT AND DISCUSSION

All of the laminate conditions of 20 layers were built up without top surface oxidation. However, the four conditions resulted in different dimensions under different heat conditions. The laminate layer appearance is shown in Fig. 5

FIGURE 5. Laminate layer appearance (Wall Side View).

The single heat condition (Avg. 106.8 kJ/mm/layer) produced a fan appearance on a section. This is caused by the cumulative heat change effect to penetration and deposited too much material during the bead formation. As for the multi-condition sample, in the lower layer 1 – 5, the cumulative heat shaped the fan appearance and changed the penetration, but the laminate has produced a concave laminate contour and straight wall (more uniformly) depending on the heat condition in the top half of the layer (over layer 10, after mid-layer). The laminate wall macro appearance is shown in Fig. 6. According to the result presented, reducing current technique led to higher but narrow wall formation. This is due to the effect of the metal deposition when welding current decreased. This makes the laminate not to extend on width too much. In the travel speed increasing technique, it has improved the laminate dimension, but the height was decreased in the single condition (base condition) caused by the same deposition in every layer making a high penetration shown in Fig. 6.

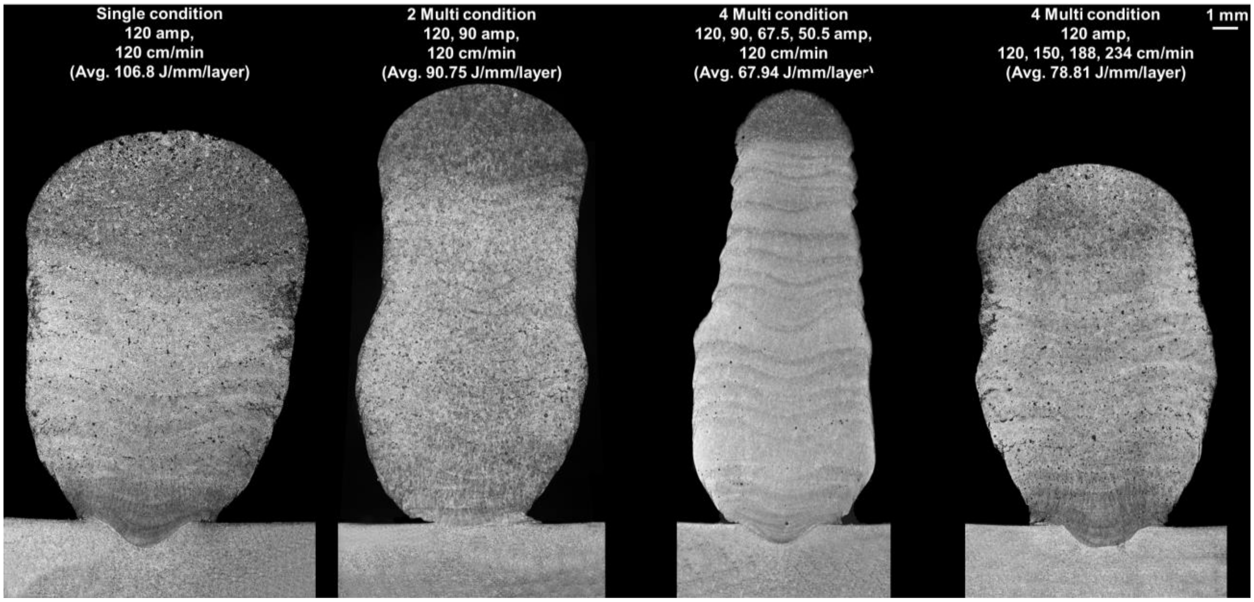


FIGURE 6. Macro laminate layer appearance (Section View).

The width and height dimensions were presented in Fig. 7. It was found that the current reducing technique led to 8 - 12 % increase in height but 34 - 45% decrease in width compared to the single condition because the lower heat condition reduces penetration (by decrease in metal deposition) and increases height deposit on the dimension. For the speed increasing technique, there was an 11% decrease in the height, the cumulative heat remained the same as the previous layer with the high metal deposit rate, which results in obtaining high penetration. Moreover, the travel speed increasing technique resulted in instability of bead formation, i.e., Bead humping on the top half layer (Over 10 layer) shown in Fig. 5. This is because of too high travel speed effect on the solidification of metal lead to irregular forms. Bead Humping does not occur in the reducing current technique as the technique decreased the deposit of the metal and kept the same build-up speed. However, the reducing current technique is used, it brings lack of fusion and overlap bead occurring under less heat input.

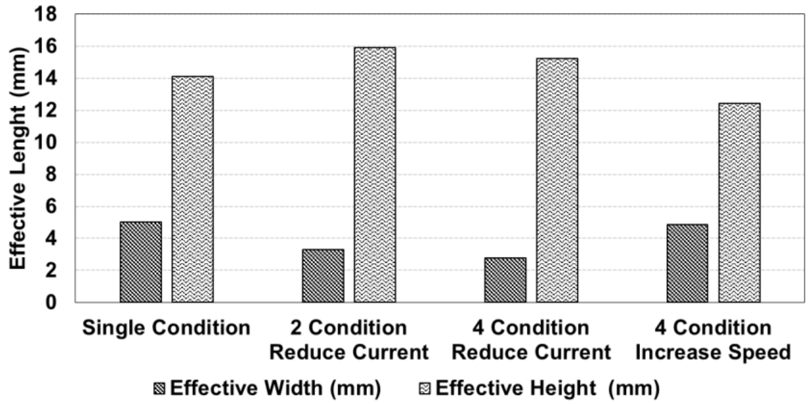
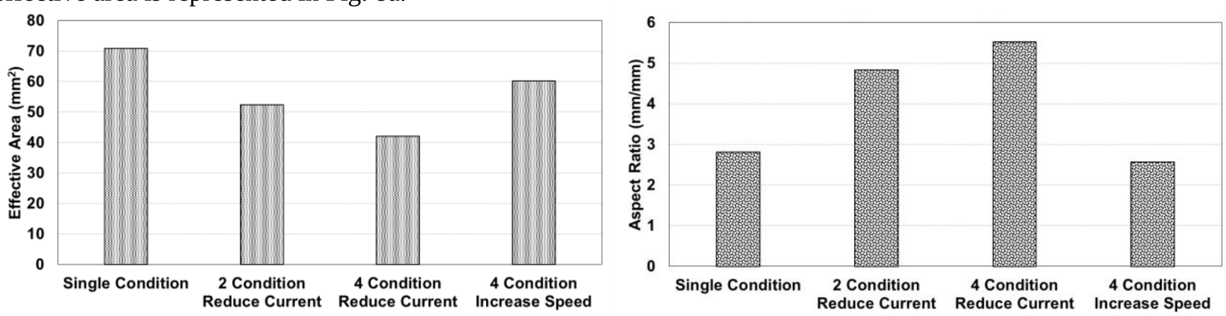


FIGURE 7. Impact of heat input technique on effective width and effective height.

The effective area decreased (25 - 40 % depending on the condition) when using the current approach of the multi-condition technique because the wire feed speed was reduced. As a result, the speed approach reduced the material deposition rate. The current reducing technique has reduced the area up to 40% on four current conditions since the amount of wire consumption has been reduced up to 27% based on a single condition. It is important to mention that the value was changed depending on the current condition (related to wire feed speed) setting. The travel speed increasing technique has reduced the effective area compering to the single condition because the bead formation pattern was changed during the build-up process and the penetration does not decrease significantly. The effective area is represented in Fig. 8a.



(a) – Effective Area (b) – Aspect Ratio

FIGURE 8. Effect of heat input technique on effective area and aspect ratio.

In Fig. 8b, the current reducing technique affects aspect ratio increase in at least 70% (significant effect on height dimension added). The travel speed increasing technique caused 8% decrease in aspect ratio as the penetration was still high and bead formation pattern was inappropriate for the build-up. However, the results indicated the possibility to develop the WAAM procedure that could build a better uniform laminate layer.

CONCLUSION

The effect of the multi-condition technique on laminate features was investigated. The finding has been concluded as follows:

1. The multi-condition of DP-GMAW could improve the uniformity of the laminate dimension.
2. The single heat condition and speed increasing technique have affected the width dimension build-up.
3. The current reducing technique had an influence on height dimension build-up. The multi-condition technique indicated the possibility of a build-up laminate layer uniformly.
4. Too high travel speed build-up is not appropriate for laminate appearance. The additive layer produced the humping beads (unstable layer formation) on the side of the laminate wall.

The study has selected the current reducing multi-condition technique as a suitable technique to improve the uniformity of the laminate wall. Besides, the 4 reducing conditions' current achieved a higher aspect ratio of 14% (even a lower height than 4% compared to 2 reducing conditions' current). Applying lower deposition of 20% with a lower current had the advantage of saving material and electrical consumption.

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