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The Adequate of Double Pulse Parameters for Aluminum Alloy Build-up Base Wire and Arc Additive Manufacturing

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Abstract

In this article has been applied the double pulse gas metal arc welding (DP-GMAW) to build-up the aluminum laminate wall base on the concept of wire and arc additive manufacturing (WAAM). The GMAW robotic has build-up the filler wire ER5356 diameter 1.2 millimeters with industrial grade argon gas shielding on aluminum 5083 substrate material. The two majorities have studied in this research were the single-pass build-up study and the multi-pass build-up study. The first study to obtain the effect of DP-GMAW parameters consist of current (ampere), voltage (volt), travel speed (centimeters per minute), frequency (Hz), duty cycle (percent) and delta current (ampere) on build-up dimension. Besides, the second study to obtain the effect of DP-condition sets on a laminate wall dimension. The study has used the dimension of bead width and bead height to represent the effect of parameters and processability. The result has been constructed in the DP-GMAW process window for single-pass forming. Moreover, the suitable DP-GMAW condition has could build-up the laminate walls has been determining.

Keywords: *DP-GMAW, Aluminum Build-up process, Additive manufacturing, Aluminum WAAM*

Introduction

The additive manufacturing (AM) has been developed the build-up process of creating or repairing the metal part of producing the complicated geometry and saving the cost of the material and investment [1 - 3]. The Additive manufacturing (AM) is the official industry standard term (ASTM F2792) for all applications of the technology. It is defined as the 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 layer, the thermal process as welding and laser melting processes has been compatible because the process had been melted the material and continuously formed the layer upon layer.

The additive manufacturing (AM) has more attention in the manufacturing industry especially to create part and prototypes. For reach the demands of the aerospace, automotive, and rapid tooling industry. The recent focus of AM research has been shifted to fabricate complex-shaped metal components, including titanium and nickel alloys that cannot be economically produced using conventional methods. The competitive position of AM for metal components relative to alternative manufacturing processes is a function of the geometrical complexity and production volume [3 - 6].

The GMAW Process has high flexibility. The process could select the many characteristics of the current signal to matching with a working material. By this way on an aluminum bead forming was a preliminary study on the comparison of the direct current (DC) and double pulse current (DP). Both of current waveform are shown in Figure 1. However, the detail about the DP current will be defined more in Figure 4. The result of welding found several of DC difficult for control a uniform of the bead. For an example of weld bead represented the DP current could form a bead uniformly than direct current as shown in Figure 1. It was concluded that the DP current has more uniform to forming bead than the DC on low heat condition. The DP has interesting in forming the laminate wall For WAAM by this reason the study has been a focus on the double pulse current to building-up aluminum alloy base additive manufacturing.

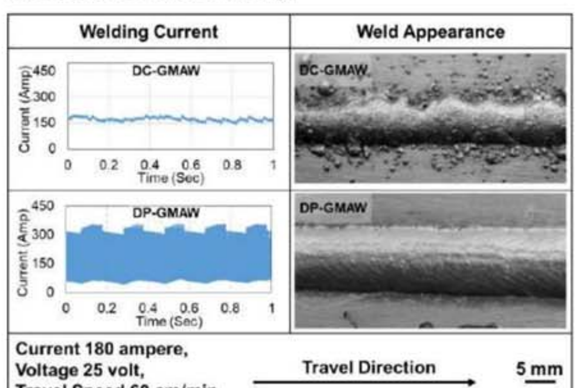


Figure 1 The GMAW Current Comparison of Weld Bead Apearance

This article has the objective to study the effect of DP-GMAW parameters on bead dimension for build-up aluminum alloy and to construct the build-up process window for single-layer. Moreover, the studying has focused the effect of heat condition on laminate wall dimension, to determine a suitable condition for the multi-layer wall.

Experimental Setup and Parameter

Experiment Material and Equipment

Aluminum alloy wire ER5356 with a diameter of 1.2 millimeters was used as the build-up material. In this study, the aluminum 5083 with a thickness of 15 millimeters used as substrate material and industrial argon gas (99percent purifier) was used to shield during process build-up. The build-up geometry had chosen the laminate thin wall weld continually layer upon layer to perform the ability of the build-up process.

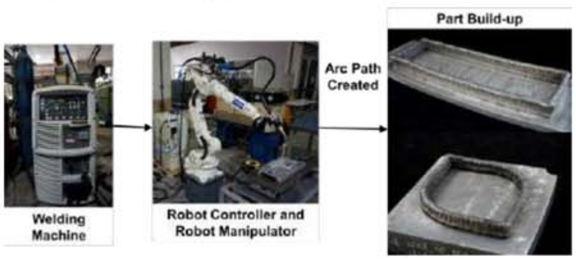


Figure 2 Experimental Setup

For the welding process, the experiment set-up consists of double pulse GMAW power supply of MEGMEET Astern 400 ADR and OTC WB-P500L. The MEGMEET Astern 400 ADR machine had a maximum current at 400 ampere up to 720 ampere and voltage 50 volt maximum adjusting. Otherside, the OTC WB-P500L had maximum pulse current pulse 400 ampere and voltage 34 volt maximum adjusting. Figure 2 shows the mapping setup of the experimental. In this case of the machine parameters were compared by heat input concept to determine the same heat condition of welding parameters. Welding robotic OTC FD-V8 was employed in controlling a precision build-up path for the single-pass and multi-layer experiment. A process was continued build from the base layer upon layer with increasing constant distance or constant layer height. The starting the first layer with used 15 millimeters of contact tip to work distance (CTWD). Figure 3 represented the schematic of the process with process variables.

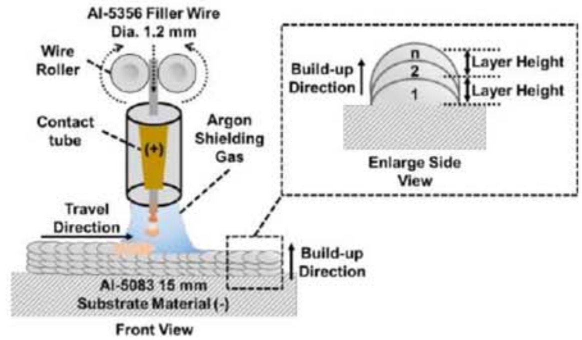
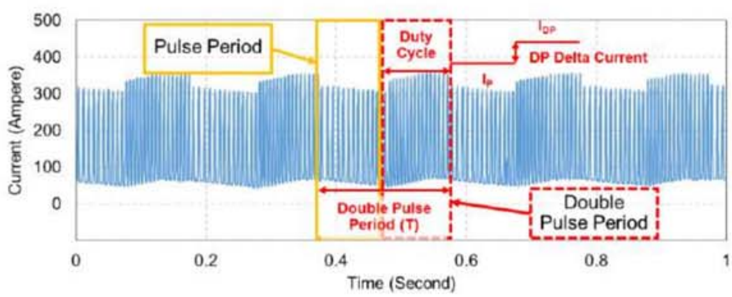


Figure 3 Schematic of the build-up process and process variables

Double Pulse Parameters

To clearly understand the effect of DP parameters. The DP current signal during build-up was detected to get an actual level of a current pattern. Calibrated current sensing with a hall sensor (current transformer) was connected through the DAC device by the sampling rate of 5000 samples per second. The computer used for converting and storing the weld signal data. The measured DP current signal clearly shown in Figure 4 that process the data acquired is a suitable monitoring system this current pattern was collected from OTC WB-P500L welding machine by used the condition of current 120 ampere, voltage 17.8 volt, travel speed 100 centimeters per minute, frequency 5 Hz, duty cycle 50 percent and delta current 30 ampere. Moreover, measuring of DP parameters consist of DP-frequency, DP-duty cycle and delta current were defined in Figure 4.



I_{DP}	Double Pulse Peak Current (Ampere)
T_{DP}	Double Pulse Duration (ms)
I_P	Pulse Peak Current (Ampere)
T_P	Pulse Duration (ms)
T	Double Pulse Cycle Time (ms) ; $T = T_P + T_{DP}$;
I_{AVG}	Average Current (Ampere) ; $I_{AVG} = (I_{DP}T_{DP} + I_P T_P)/(T_{DP} + T_P)$
DP-Frequency	Double Pulse Frequency (Hz) ; F = 1/T (1/Second)
DP-Duty Cycle	Double Pulse Current Duration In One Cycle/Period (%)
DP-Delta Current	Double Pulse Delta Current $I_{DP} - I_P$ (Ampere)

Figure 4 Double Pulse Gas Metal Arc Welding Parameters

Experiment Parameters Study

The experiment of the single-pass experiment has studied the effect of DP-GMAW variable consist of the current range 5 to 80 ampere, voltage 20 to 27 volt, travel speed 20 to 160 centimeters per minute, frequency 0.5 to 10 Hz and duty cycle 30 to 70 percent and delta current 3 to 45 ampere. The design of the experiment has chosen Taguchi's design (Orthogonal Array Design). Set of the first studied variables shown in Table 1.

Table 1 Single-pass Experiment Parameters

Single-pass Study Parameters						
	Current Study	Voltage Study	Frequency Study	Duty Cycle Study	Delta Current Study	Travel Speed Study
Current (ampere)	120, 140, 160, 180, 200, 210	180	180	180	180	140
Voltage (volt)	25	15, 17, 19, 21, 23, 25, 27	21	21	21	19
Frequency (Hz)	5	5	1, 5, 10	5	5	5
Duty Cycle (%)	50	50	50	30, 50, 70	50	50
Current Intensity (%) or Cal. Delta Current (ampere)	14	14	14	14	3, 8, 14, 16, 32 or 4, 14, 23, 24, 45	14
Travel Speed (cm/min)	60	60	60	60	60	20, 60, 100, 140, 160
Fixed Welding Parameters						
CTWD (mm)	15					
Argon Shielding Gas Flow (LPM)	15					
Torch Angle (Degree)	90					

The multi-layer build-up experiment was studied in effect of DP-GMAW variable consist of 4 conditions of DP parameters with constant DP parameters consist of frequency 5 Hz, duty cycle 50 percent, delta current 30 ampere and layer height 1.5 millimeters. Set of the multi-layer studied parameters had shown in Table 2.

Table 2 Multi-layer Experiment Parameters

Multi-layer Study Parameters			
Condition 1 Current (ampere) Voltage (volt) Travel Speed (cm/min)	 120 17.8 120	Condition 2 Current (ampere) Voltage (volt) Travel Speed (cm/min)	 120 17.8 100
Condition 3 Current (ampere) Voltage (volt) Travel Speed (cm/min)	 140 18.6 100	Condition 4 Current (ampere) Voltage (volt) Travel Speed (cm/min)	 140 18.6 60
Welding Parameters			
Layer Height (mm)	1.5		
Frequency (Hz)	5		
Duty Cycle (%)	50		
Delta Current (ampere)	30		
Start CTWD (mm)	15		
Argon Shielding Gas Flow (LPM)	15		
Torch Angle (Degree)	90		

The laminate slop or difference height occurs when the build-up parameter not suitably (Most of the high heat condition) causes from the molten aluminum overflow or penetration change. In this study determine the different height in term of the head and tail difference height have defined to represent the slope of the laminate wall dimension.

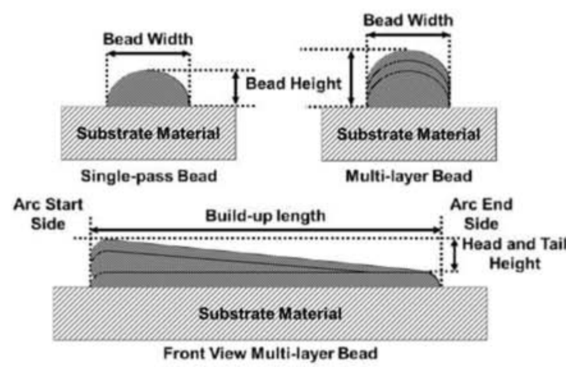


Figure 5 Single-pass and Multi-layer Bead Geometry

Build-up Dimension

The dimension was to represent the ability and effect of the process parameters. Figure 5 was illustrated the measured dimension of the single-pass bead and multi-layer bead in the experiment. Moreover, bead width and height for multi-layer was measure in the minimum dimension define as the effective dimension. In this study was not measured the penetration depth due to the study focusing on bead effective formation and the penetration does not useful for AM process.

Experimented Results and Discussion

Single-pass

The effect of current on the experiment, the welding current in the range of 120 - 210 ampere, with other constant parameters as shown in table 1, the spatter was occurs at the weld toe as a too low current and improper voltage. The increasing of welding current results in a welding width and height increased. Figure 6 showed the weld appearance on current change. However in range of 120 – 210 ampere obtained excellent bead formation, but if lower current adjusted might occur lack of fusion even travel speed low or high.

In the same way with the higher current might occur uncontrollable bead two types are overflow bead (Too high current with low travel speed) and the humping bead (Too high current with high travel speed)

The effect of voltage on the experiment, the arc voltage was in the range of 15 - 27 volt, with providing fixed parameters as shown in table 1. It was found that adjusting the voltage at a low 15 volts resulted in unevenness of the weld edge and adjusting the voltage From 25 to 27 volts, resulting in the spatter of the weld toe. The increasing the arc voltage results in an increase on the bead width, but the bead height is decreased. Figure 6 showed the weld appearance on voltage change.

The effect of travel speed on the experiment, the travel speed was in the range of 20 - 160 centimeters per minute with providing fixed parameters as shown in table 1. The welding speed at 20 centimeters per minute results in uneven welding bead overflow due to too slow welding speed. Moreover, the welding speed of more than 160 centimeters per minute results in bead humping (non-uniform bead) due to too fast speed. The travel speed increases the bead width and bead height is decreased. Figure 6 showed the weld appearance on travel speed change. The travel speed is one of the main factors for the process due to the speed could control heat to forming a bead and could setting productivity rate.

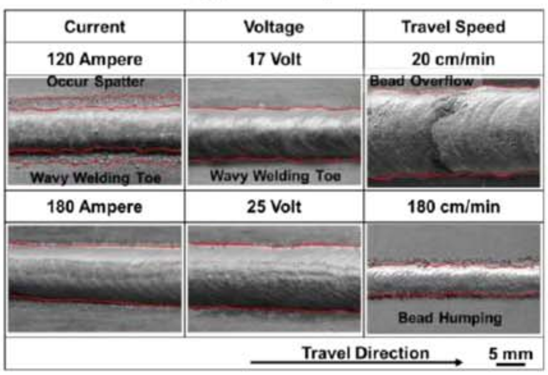


Figure 6 Bead Appearance on Current, Voltage and Travel Speed Change

The effect of frequency from the experiment, the frequency was in 1 - 10 Hz, with constant parameters as shown in Table 1. The result found that increased frequency adjustment resulted in an increase in the number of double pulses cycle in a second with a shorter duration. The low frequency at 1 Hz occurs wavy weld edge due to the difference deposition between pulse and double pulse (interval) too long. Which increases the frequency does not significantly increase in bead width and bead height. Figure 7 showed the weld appearance on frequency change. For penetration depth could assume is not significantly affected by the concept of frequency when increased is not change with the heat input.

The effect of the duty cycle from the experiment, the duty cycle was in the range of 30 - 70 percent by providing fixed parameters as shown in table 1. The increase in the duty cycle the double pulse duration was increased. The increasing of the duty cycle does not affect the bead width and the bead height has increased significantly. Figure 7 showed the weld appearance on duty cycle change. The circle mark had indicated the pore (diameters less than 1 mm) on weld toe as a lack of fusion. For penetration depth by the concept of duty cycle could assume is when increase duty cycle will affect the penetration increase.

The effect of delta current from the experiment, the value of the delta current in the range of 4 - 45 ampere with providing fixed parameters as shown in table 1. Note that the study did not focus on high delta current because the too high delta current occurs the weld bead not uniformly as bead flow. For increasing the delta current, the difference of current between the pulses current and the double pulse current are more different. The low delta current 4 ampere does results in exceeding the curved welding toe because of heat does not enough for forming. Moreover, the high delta currents could make the bead pattern look like fish scales. Which increases the delta current does not affect the decrease of bead width and significant bead heights. Figure 7 showed the weld appearance on delta current change. The circle mark had indicated the pore (diameters less than 1 mm) on weld toe as a lack of fusion. For penetration by the concept of delta current could assume is the penetration depth will increase when delta current increase.

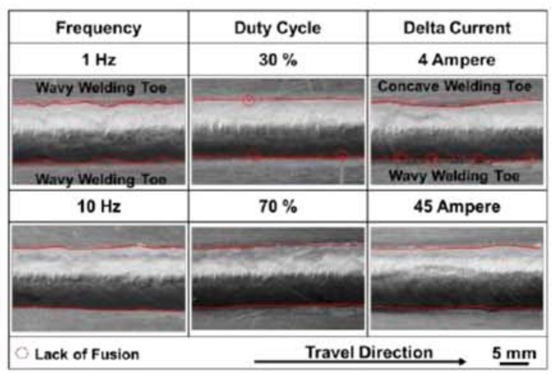


Figure 7 Bead Appearance on Frequency, Duty cycle and Delta Current Change

From the single-pass build-up experiment, the influence of DP-GMAW parameters on the weld bead dimension. The variables have significantly mainly affected the bead geometry include welding current, arc voltage, and travel speed. Alternatively, the variable that does not affect the bead geometry significantly consists of the frequency, duty cycle, and delta current. Figure 8 presents an overall effect of DP-GMAW parameters on the bead dimension. Therefore the study has created a mapping for setting parameters. The process window has been constructing further the studies in the current of 60 - 210 ampere and Travel speeds of 20 - 180 centimeters per minute.

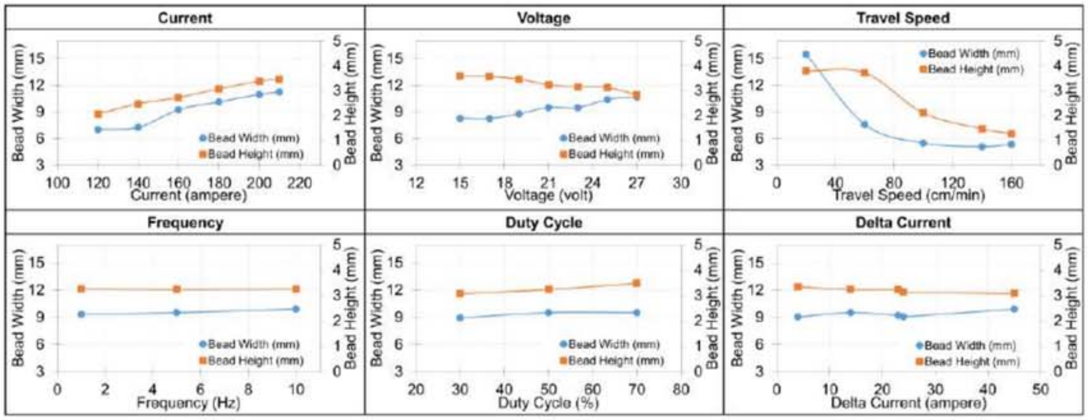


Figure 8 Effect of DP-GMAW Parameters on Bead Dimension

For arc voltage recommend adjusting from the welding machine to maintain the stability of the arc perform. The results from the experiment can create a process window for aluminum single-pass build-up as present in Figure 9. The mapping divided into four main areas consist of lack of fusion area, adequate area, humping bead area, And overflow bead area. For the multi-layer experiment, the parameters in the adequate area have been chosen for the multi-layer build-up as 120 to 140 ampere with travel speed 60 to 120 centimeter per minute for multi-layer build-up, because of the parameters condition is low heat for the single bead forming.

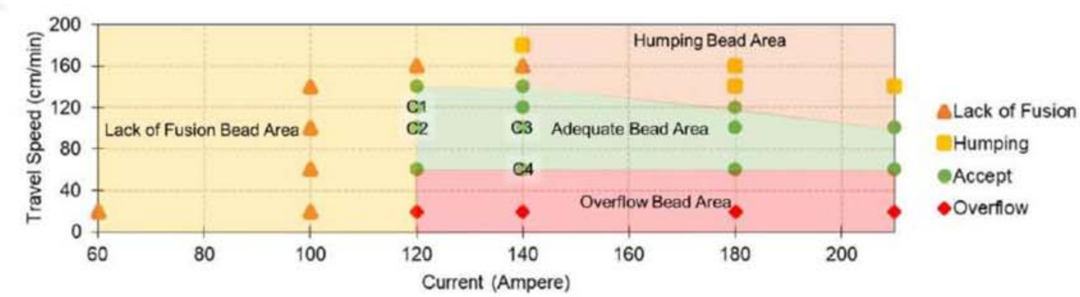


Figure 9 DP-GMAW Process Parameters Area for Aluminum Single-pass Bead Forming

Multi-layer Build-up

The parameters condition consist of current 140, 120 ampere and travel speed 60, 100, 120 centimeters per minute with constant parameters as frequency 5 Hz, duty cycle 50 percent, the delta current of 140 ampere and layer height 1.5 millimeters. In the high heat condition 4 (0.2604 kJ/mm) occur bead flow and laminate wall slope cause cumulative heat on the laminate appearance as represented in the bottom right side of Figure 10. To avoid the bead flow could reduce some of the heat by increase travel speed as condition 3 (0.1562 kJ/mm) or decrease current as condition 2 (0.1281 kJ/mm) or apply both like condition 1 (0.1068 kJ/mm).

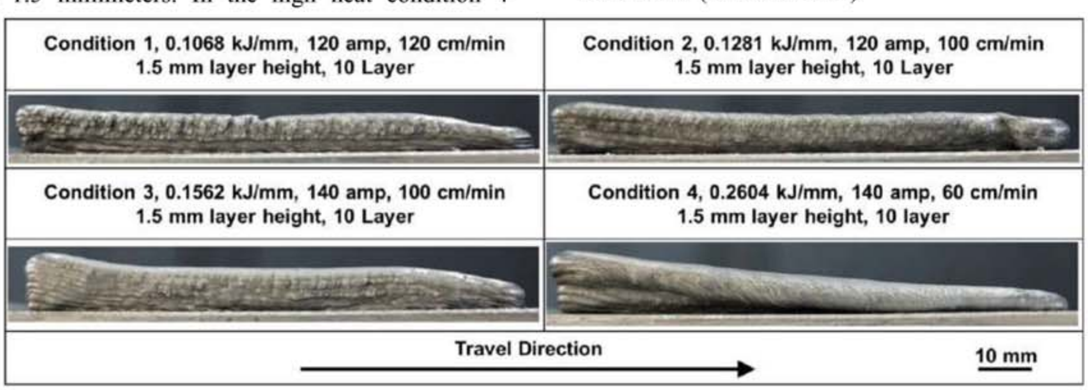


Figure 10 Laminate wall Appearance In Each Condition

The effect of heat condition on laminate dimension arranged by heat input. Found the increase of heat condition was decrease the effective laminate height. Besides, the head and tail difference height have increased. Cause of the high heat condition had more cumulative temperature effect on bead formation pattern or penetration change occur laminate slope. The relation of heat condition and laminate dimension represented in Figure 11.

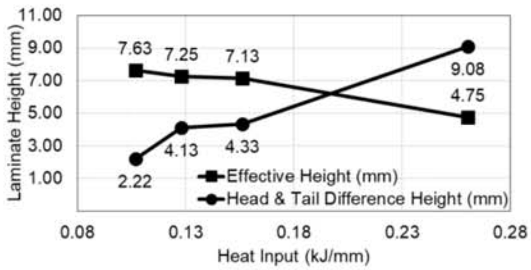


Figure 11 Heat Input Condition Effect on Laminate Head and Tail Difference Height

The recommendation for the layer height on laminate dimension should follow the laminate height properly. If not the problem for too low layer height might occur contact tip stuck and for too high layer height might have lack of gas shielding cause to bead oxidation and uncontrollable of bead formation.

In Figure the heat condition 1 (0.10 kJ/mm/layer) has the lowest difference height (2.22 mm) with highest effective height (7.63 mm) could determine in term of the adequate condition to build-up aluminum alloy. However, this study perspective on process performance, in the case of metallurgy cross-section evaluation and mechanical properties testing will discuss on another report. Moreover, the process has the advantage by comparing CMT on single bead dimension [7] under the average heat input between 0.180 – 0.306 kJ/mm found by bead width the DP had more 18% larger and bead height more 20% higher.

Figure 12 is a workpiece had been build-up by the adequate condition the workpiece could be build-up uniformly dimension.

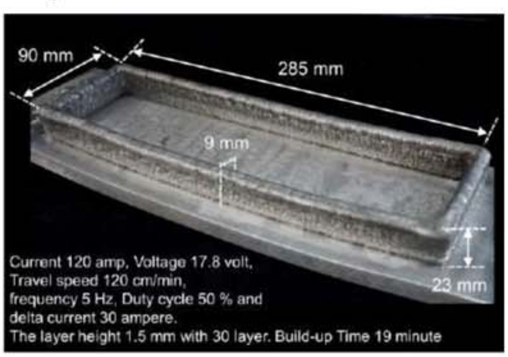


Figure 12 Workpiece by the Suitable DP-GMAW Parameters

Conclusion

The DP-GMAW parameters were investigated for the effect on build-up bead dimension for the single-pass build up and the effect on multi-layer laminate dimension. It can be concluded from the present research that:

1. The main effect of process parameter on the bead dimension was consist of current, voltage and travel speed. The main parameters should be adjusted in a range of 120 – 210 ampere and travel speed 60 – 140 centimeters per minute
2. The double pulse variable consists of frequency, duty cycle and delta current were not significant effect on bead dimension. However, the DP-variable should be adjusted on the adequate range to maintain the uniformly of bead dimension and appearance. The recommend for frequency 5 – 10 Hz, duty cycle 30 – 70 percent and delta current 15 – 40 ampere.
3. Increasing the heat condition was effective to decrease laminate height.
4. The heat condition was the main effect on a laminate slope. To reduce the laminate slope should be used the lowest heat condition as possible for build-up. This paper had existed 120 ampere of current, voltage 17.8 volt, travel speed 120 centimeter per minute, frequency 5 Hz, duty cycle 50 percent, delta current 30 ampere and layer height 1.5 millimeters.

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