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Optimisation of the wire feed rate during pulse MIG welding of Al sheets

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ABSTRACT

Purpose: This paper aims at optimizing the wire feed speed against the welding speed during the pulse-MIG (Metal Inert Gas) lap joint fillet weld of 1.6 mm aluminium alloy typically used for the light-weight car body.
Design/methodology/approach: Welding experiments were conducted with various wire feed speeds of 0.5 m/min, 1.0 m/min, and 1.5 m/min, and the bead characteristics were evaluated. As shape factors of the weld bead, the bead width, back bead width, and bead cross-section area were measured. According to the weld quality and defined objective functions, the wire feed speed was optimized for various welding speeds.
Findings: The wire feed speed that induces the optimum weld quality was found with welding speeds of 0.5 m/min, 1.0 m/min, and 1.5 m/min. The optimum lap welding conditions were then suggested for 1.6 mm aluminium alloy considering the productivity and quality.
Research limitations/implications: The optimization will be extended to various aluminium alloys and the optimized results will be stored in the Al welding database of the intelligent welding power source development.
Practical implications: With the increase of the welding speed for aluminium sheet welding, the corresponding wire feed speed should increase as well. On the other hand, it is clear that the maximum value of the objective function has decreased.
Originality/value: This research revealed the relationship between the welding speed and the wire feed speed considering the welding productivity and quality. In addition, the criterion to evaluate the degree of weldability during lap welding is suggested according to the quality and objective functions.
Keywords: Welding; Aluminium sheet metal; Pulse MIG (Metal Inert Gas) welding

1. Introduction

Recently, as people have become more interested in pollution and environmental matters throughout the world, automotive manufacturers have actively conducted numerous studies regarding methods to improve fuel efficiency through vehicle weight reduction measures as well as other approaches [1-2].

One of the most versatile ways to reduce the weight of a vehicle is to use light and corrosion-proof aluminium alloys for the body [3-8]. As aluminium alloys generally have a low melting point and high thermal conductivity and diffusivity, however, burn-through may occur due to the high heat input during the conventional constant voltage MIG (Metal Inert Gas) welding of aluminium sheets. In contrast, ODPP (One Drop Per Pulse) MIG welding, as a type of pulse welding, can be an alternative in aluminium sheet welding, as it minimizes the heat input by controlling droplet transfer with well-adjusted welding conditions in which a single droplet is detached per pulse [9-11].

This paper aims at optimizing the wire feed speed with different welding speeds during the ODPP MIG lap welding of 1.6mm-thin aluminium sheets of the type that are prevalently used for car bodies.

2. Experiments

2.1. Experiments setup

The experimental setup and welding conditions are given in Table 1.

As shown in Fig. 1, aluminium(6k21) sheets with a thickness of 1.6mm were lap-welded with the welding torch perpendicularly set on a base metal as in robot teaching in a production line. The chemical compositions of the Al 6k21 alloy are shown in Table 2.

Table 3 shows 10 welding conditions chosen in the range of 2.5m/min – 7.5m/min in terms of the wire feed speed. Each pulse parameter demonstrates the ODPP welding condition with each wire feed speed.

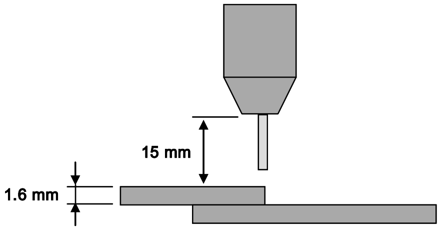


Fig. 1. Schematic illustration of Experimental setup

Table 1.
Experiments setup

Welding power source	500A, Inverter
Type of wire	Solid wire 1.2Φ (Al 4043)
CTWD	15 mm
Shielding gas	100% Ar-20l/min
Base metal	Al 6K21- 1.6mm

Table 2.
Chemical composition of Al 6k21 alloy (weight, %)

Si	Fe	Cu	Mn	Mg	Zn	Al
0.03	0.08	0.33	0.01	5.60	0.01	Bal.

3. Results and discussion

3.1. Bead shapes

This paper evaluates the welding quality using the shape factors of weld beads, which determine the mechanical characteristics of the weldment [12-15]. Among the bead shape factors, the bead width, back bead width and cross-section area are considered. Using the conditions in Table 2, welding experiments were conducted at welding speeds of 0.5m/min, 1.0m/min, and 1.5m/min. The resulting bead surfaces and cross-sections are shown in Tables 4 and 5, respectively. As shown in Table 4, the bead width increases when the wire feed speed increases. In addition, back bead widths were observed above a certain level of wire feed speed. During the assembly of a car body, the back bead formation is avoided as much as possible. Table 5 shows the bead cross-sections under the conditions shown in Table 2. As wire feed speed increases, the bead cross-section area becomes wider. If the wire feed is slow relative to welding speed, incomplete penetration is observed. If the wire feed is fast, in contrast, excessive melting will occur. Therefore, this paper aims to determine optimum welding conditions that meet the three shape factors of the weld bead by analyzing the results in Tables 4 and 5.

3.2. Quality and objective function

The weld quality functions were designed as shown in Fig. 2 using the aforementioned bead shape factors (bead width, back bead width, and bead cross-section area) to find optimum conditions in which the desired bead shapes of penetration can be achieved. Here, W_b, W_{bb}, and A_b indicate the 'Bead Width', 'Back Bead Width,' and 'Bead Cross-section Area', respectively.

$$J = \hat{j}(W_b) + \hat{j}(W_{bb}) + \hat{j}(A_b) \quad (1)$$

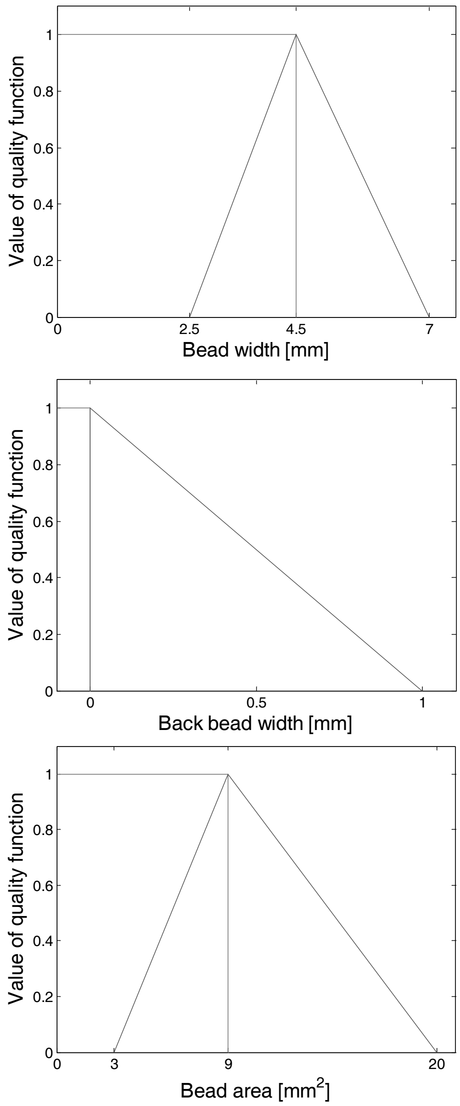


Fig. 2. Quality functions for bead shapes

Table 3. Pulse parameters

No.	1	2	3	4	5	6	7	8	9	10
Base current [A]	28.1	38	47	56	65	71.0	77.1	83.2	89.4	95.5
Pulse current [A]	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
Pulse current Time [ms]	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Pulse duty[%]	9.8	11.7	13.8	15.9	18.0	21.0	24.0	27.0	32.4	33.0
Frequency [Hz]	54.3	65	76.6	88.2	100	116.6	133.2	150	166.6	183.2
Wire feed speed[m/min]	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Voltage command value [V]	14.5	14.8	15.0	15.3	15.6	15.9	16.1	16.4	16.7	17.

Table 4. Bead surfaces for various welding conditions

WS	0.5 m/min		1.0 m/min		1.5 m/min	
WFS	Bead	Back bead	Bead	Back bead	Bead	Back bead
2.5m/min	2.98mm	0mm				
3.0m/min	4.74mm	0mm	2.63mm	0mm		
3.5m/min	5.25mm	0mm	3.51mm	0mm	2.98mm	0mm
4.0m/min	6.49mm	2.46mm	4.21mm	0mm	3.16mm	0mm
4.5m/min	8.25mm	6.14mm	5.26mm	0mm	3.51mm	0mm
5.0m/min	8.45mm	7.19mm	6.14mm	2.28mm	4.21mm	0mm
5.5m/min			6.49mm	4.91mm	5.79mm	2.98mm
6.0m/min			7.19mm	5.61mm	5.96mm	3.16mm
6.5m/min			7.54mm	6.67mm	6.14mm	4.74mm
7.0m/min			7.69mm	7.72mm	6.16mm	5.09mm

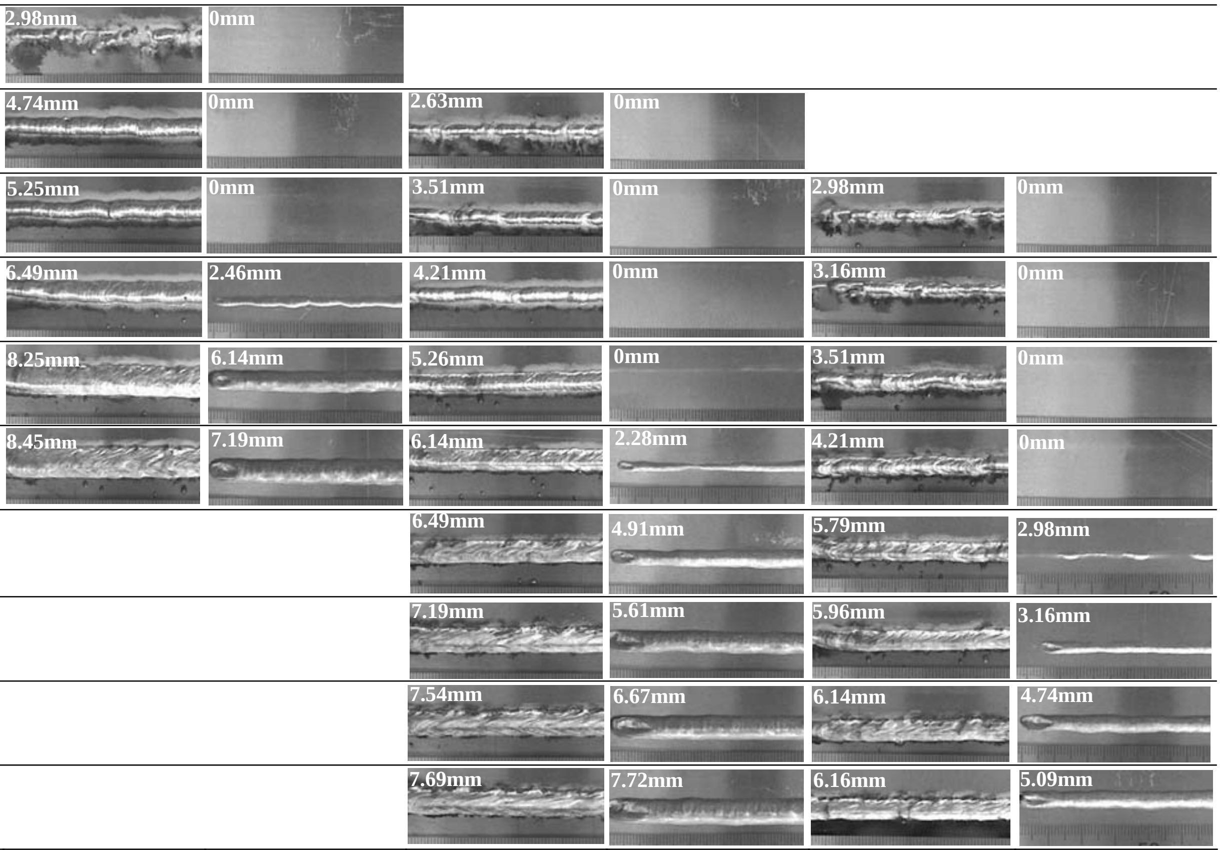
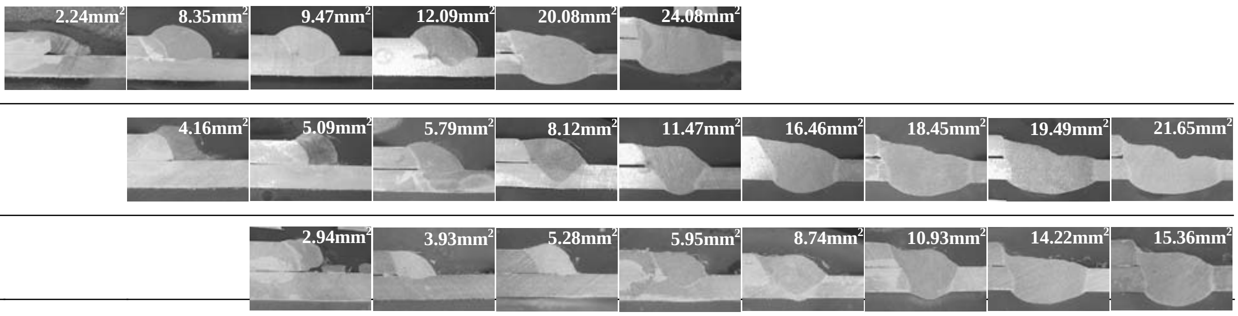


Table 5. Bead cross-section area for various welding conditions

WS / WFS	2.5 m/min	3.0 m/min	3.5 m/min	4.0 m/min	4.5 m/min	5.0 m/min	5.5 m/min	6.0 m/min	6.5 m/min	7.0 m/min
0.5 m/min	2.24mm²	8.35mm²	9.47mm²	12.09mm²	20.08mm²	24.08mm²				
1.0 m/min		4.16mm²	5.09mm²	5.79mm²	8.12mm²	11.47mm²	16.46mm²	18.45mm²	19.49mm²	21.65mm²
1.5 m/min			2.94mm²	3.93mm²	5.28mm²	5.95mm²	8.74mm²	10.93mm²	14.22mm²	15.36mm²



Eq. (1) defines an objective function that evaluates the weld quality using the normalized weld quality function values in Fig. 2. The objective function consists of the sum of the bead width, back bead width, and bead cross-section area. If the objective function value is 3, the weld quality is ideal.

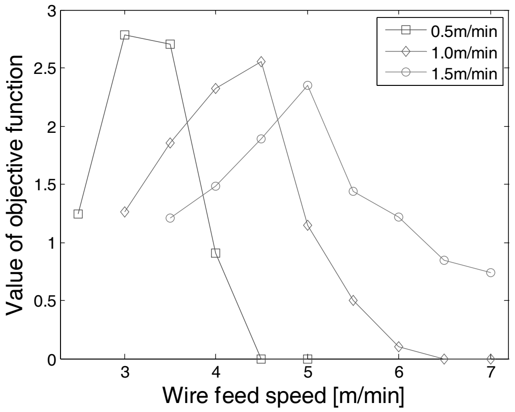


Fig. 3. Value of objective function for wire feed speed

Fig. 3 demonstrates the value of the objective function according to the wire feed speed at each welding speed. The maximum objective function value was 2.787 at a welding speed of 0.5m/min (wire feed speed: 3m/min), 2.549 at a welding speed of 1.0m/min (wire feed speed: 4.5m/min), and 2.346 at a welding speed of 1.5m/min (wire feed speed: 5m/min). As the welding speed increases, the wire feed speed increases and the maximum objective function value decreases. Additionally, the range of the adequate wire feed speed becomes narrower as the welding speeds increases.

4. Conclusions

The wire speeds at different welding speeds were optimized for the pulse-MIG lap welding of 1.6mm aluminium alloy in this paper. Conclusions can be summarized as follows.

1) Under the same welding speed, as wire feed speed increases, the bead becomes wider and the bead cross-section area increases. As wire feed speed increases, the penetration changes from incomplete penetration to excessive melting.
2) According to an analysis of the objective function value using the weld quality function, the maximum value of the objective function decreases and the range of adequate wire feed speeds narrows as the welding speed increases.
3) By maximizing the objective function value, the wire feed speed was optimized at welding speeds of 0.5m/min, 1.0m/min, and 1.5m/min.

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