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Arc characteristics and behaviour of metal transfer in pulsed current GMA welding of aluminium alloy

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Abstract

The variation in arc characteristics, stability in shielding of arc environment and behaviour of metal transfer with variation in pulse parameters have been studied by high speed video photography during GMA weld deposition using Al–Mg filler wire. The effect of pulse parameters has been studied by considering their hypothetically proposed summarised influence defined by a dimensionless factor $\phi = [(I_b/I_p)ft_b]$, mean current and arc voltage. The arc characteristics studied by its root diameter, projected diameter and length, the instability of shielding environment reflected by its puncturing through vortex formation and the behaviour of metal transfer noted by the diameter and velocity of droplet at the time of detachment and deposition in weld pool have been found to vary significantly with the pulse parameters. At a given pulse parameter the experimentally measured values of the behaviour of metal transfer are found well in agreement to their corresponding theoretical values estimated through mathematical expressions. The observation may help in understanding the weld characteristics with respect to variation in pulse parameters which may be beneficial in using pulsed current GMAW to produce desired weld quality.
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Keywords: GMAW; Pulsed current; Effect of pulse parameters; Arc characteristics; Shielding of arc environment; Metal transfer; Experimental measurement; Theoretical estimation

1. Introduction

The advantage of using pulsed current gas metal arc welding (P-GMAW) to improve the weld characteristics of different ferrous and non-ferrous alloys over those observed in the conventional continuous current gas metal arc welding (GMAW) is fairly well established by several workers [1–16]. But it is often pointed out that the benefits of employing P-GMAW process to improve the weld quality largely depend on using appropriate pulse parameters, where a deviation from that may harm the weld characteristics [3–16]. It primarily happens due to their significant influence on porosity content and thermal behaviour of the weld [4,5,13,15,17–20] basically dictated by the arc characteristics and the behaviour of metal transfer [21]. The porosity formation in weld deposit is explained by air aspiration in arc environment through puncture in shielding gas jacket due to a negative pressure created by the turbulence in it caused by a fluctuation of arc pressure under the pulsed current. Whereas, the thermal behaviour of the weld largely depends upon arc characteristics and the behaviour of metal transfer which significantly influences the chemistry, microstructure, geometry and stresses of the weld. The difficulties in right selection of pulse parameters to control all these phenomena often restricts the wide application of this process in weld fabrication of different materials due to paucity of detail knowledge of the arc characteristics and the behaviour of metal transfer in P-GMAW process.

During P-GMAW using a modern commercial welding power source the simultaneous influence of its basic parameters, such as the mean current (I_m), base current (I_b), pulse current (I_p), pulse time (t_p) or pulse off time (t_b) and pulse frequency (f), on each other [22] introduces criticality in selection of pulse parameters affecting the weld characteristics [3–16]. However, while addressing these difficulties it is amply justified [9–16,22–28] that the weld characteristics of the P-GMAW can be fairly well estimated by correlating them with a summarised influence of pulse parameters, defined [29] by a dimensionless factor $\phi = [(I_b/I_p)ft_b]$ where, $t_b = [(1/f) - t_p]$. Thus, this hypothetical factor derived from the energy balance concept of the process

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may improve the acceptability of pulsed current GMAW process. It may be considered that the use of P-GMAW by right selection of pulse parameters [30] confirming the desired ϕ can produce an intended quality in weld fabrication. However, in order to choose proper pulse parameters through right selection of ϕ, it is also imperative to understand the influence of pulse parameters on the arc characteristics and metal transfer behaviour of the process affecting the weld quality. In view of its necessity the effects of ϕ at various pulse parameters including the arc voltage on the characteristics of arc and the behaviour of metal transfer in P-GMAW process using 1.6 mm diameter Al–Mg filler wire in argon shielding have been studied. The study provides a basic understanding to analyse the mechanism of variation in weld characteristics dictated by the summarised influence of pulse parameters in P-GMAW process, which may also form a basis of improved automation [21] of this process.

Table 1
The measured pulse parameters giving different ϕ studied in this work

ϕ	I_m (A)	I_b (A)	I_p (A)	t_p (ms)	t_b (ms)	f (Hz)	Arc voltage (V)
0.053	159	33	240	9.1	5.9	66	21
0.1	159	53	296	7.0	9.1	60	20
0.198	160	92	328	4.2	10.0	70	21
0.248	161	107	327	3.3	10.4	73	22
0.430	168	145	310	0.98	12.6	73	21
0.062	220	54	315	21.1	12.2	30	20
0.112	215	80	368	14.9	16.0	32	22
0.204	213	122	410	7.6	17.1	40	22
0.254	212	144	417	4.6	14.1	53	23
0.429	212	191	411	1.2	14.8	62	21
0.059	258	72	332	9.9	3.8	72	20
0.108	263	98	387	8.8	6.6	64	25
0.190	254	141	444	5.7	7.6	75	23
0.238	265	161	456	4.1	8.2	79	26
0.385	262	220	473	1.8	9.6	88	23

2. Experimental

Studies on arc characteristics and behaviour of metal transfer in P-GMAW was carried out by bead on plate weld deposition on 10 mm thick Al–3Mg AW 5754 rolled plate using (REHM Megapulse 500) commercial welding power source and 1.6 mm diameter Al–4.5 MgMn (5184) filler wire with DCEP at electrode extension of 15 mm having argon shielding at a flow rate of 0.0003 $m^3 s^{-1}$. The deposition of weld bead was performed by operating the power source at certain pulse parameters estimated by a software [30] giving base current (I_b), pulse current (I_p), pulse time (t_p), pulse frequency (f) and mean current (I_m) with respect to the wire feed rate for a satisfactory arc stability where the arc voltage was left free to vary for balancing energy distribution in the process. Accordingly the welding was carried out at suitably varied ϕ lying in the range of 0.053–0.43 at different mean currents of the order of 162 ± 4, 215 ± 3 and 260 ± 4 A. The range of ϕ was decided in consideration of the pulse parameters giving satisfactory arc stability [23,31] and the comparatively lower and higher range of mean currents was selected on the basis of earlier experience [32] of minimum and maximum thermal intensity of the process necessary to produce sound weld by avoiding lack of fusion and excessive oxidation of weld metal, respectively. For the filler wire used in this work the wire feed rate (W_F) for a given mean current (I_m) was estimated by using an amply verified [30] empirical correlation as follows:

$$I_m = 0.031 W_F + 0.1001 \quad (1)$$

The pulse characteristics, such as I_p, I_b, t_p and f were measured with the help of a transient recorder (maximum resolution of 1 MHz) fitted with the electrical circuit of the welding set up. The arc voltage and the I_m were estimated as mean values of the voltage and current plots, respectively of the pulse behaviour captured by the transient recorder. The typical values of measured pulse parameters giving different ϕ of measured pulse characteristics considered in this work are presented in Table 1. During welding the arc environment was video graphed with the help of a high speed camera operated at a speed 10^4 frames per second.

The nature of variation in arc characteristics and the behaviour of metal transfer with the change in pulse parameters have been studied on the high speed video-graphs of the welding. The arc characteristics defined by its root diameter, projected diameter and length was suitably measured by computerised technique applied on every photograph taken at each welding parameter as schematically shown in Fig. 1. The behaviour of metal transfer was also studied by suitable measurement of diameter of the droplets and their velocity of transfer from the electrode to the weld pool by computerised technique applied on every frame of the video-graphs revealing the transfer of droplet in the background of the glair of arc at any welding parameter. The droplet velocity was evaluated by measuring the shifting of its position by travel on frame to frame basis at the given speed of video-graphy. The velocity of metal drop at the time of detachment (V_i) from electrode was evaluated from the distance of its travel measured in two consecutive frames of video-graph from the point of detachment, whereas the velocity (V_{de}) of metal drop at the time of deposition was evaluated on the basis of measured distance of travel in two consecutive frames of video-graph prior to its deposition in weld pool. At a given welding parameter the average velocity of metal drops during their travel from the point of detachment to deposition in weld pool is also studied by estimation of their velocity on consecutive frames as stated above. The velocity in succeeding frame (V_s) was estimated as

$$V_s = [V_p^2 + 2(a + g)h]^{0.5} \quad (2)$$

where V_p is the estimated velocity in preceding frame, h is the distance of travel in between two consecutive frames, g is the gravitational acceleration and a is the

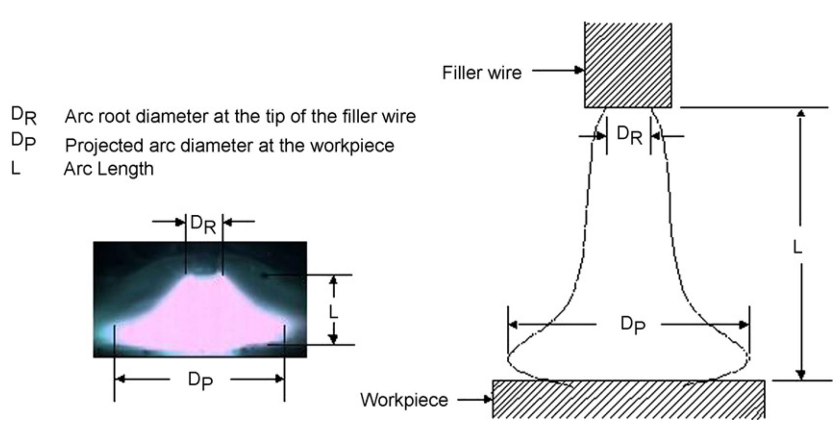

Fig. 1. Schematic diagram showing measurement technique of arc characteristics.

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