COMPUTER AIDED PULSED CURRENT GMA WELDING OF ALUMINIUM ALLOYS

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ABSTRACT

A user friendly software has been developed to select the pulse parameters for a given weld quality on the basis of empirical correlations amongst the pulse parameters and algorithms in reference to a summarised influence of pulse parameters defined by a dimensionless factor. The software enable to understand the controll of pulse parameters to maintain a stable arc for a desired weld quality of Al-Mg alloy deposit, currently considered as porosity content of it. The software has been sucessfully tried to operate a modern pulsed current GMAW power source in producing weld within a desired level of porosity content. The understanding over the characteristics of the variation in pulse parameters and their control with the help of software has been discussed to provide confidence in more wide use of pulsed current GMAW to produce weld of desired quality.

1. INTRODUCTION

The superiority of pulsed current gas metal arc welding (GMAW) in improving various characteristics of different ferrous and non-ferrous weld and weld cladding over those observed in case of using the conventional continuous current GMA welding is well known [1-16] by now. However, in case of pulsed current GMA welding of different type of material with varying section size and position of welding it is often pointed out that the benefits of employing pulsed current on weld quality is achieved by using certain pulse parameters and any significant deviation from them worsens the situation [3-16]. Because of this, the wide acceptance of this process in fabrication of different materials is largely handicapped by the criticality in selection of pulse parameters. In pulsed current GMAW 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) are the primary parameters affecting the weld characteristics [3-16]. It is observed that the role of these parameters on weld characteristics is not straightforward in nature due to their simultaneous influence on each other in modern commercial GMA welding power sources [17]. However, by addressing these difficulties it is amply justified [9-21] that the effect of pulsed current GMAW on weld characteristic can be estimated by correlating it with a summarised influence of pulse parameters, defined [22] by a dimensionless factor $\phi = [(I_b / I_p)f\ t_b]$ where, $t_b = [(1/f)-t_p]$. Thus, it may be considered that operating a GMAW power source at right pulse parameters conforming desired ϕ could produce an intended quality of weld. But, the selection of proper combination of pulse parameters in this regard, giving smooth welding with acceptable arc stability is a quite complicated task due to involvement of many pulse parameters having simultaneous influence on each other. Hardly any commercially available pulsed current GMAW power source has user-friendly option for selection and designing of pulse parameters satisfying required condition of weld deposition for a desired quality. In this regard a computerised solution through suitable software, which may work on the basis of empirical expressions and algorithms correlating the pulse parameters with respect to the factor f, may be very much useful.

In view of the above an effort has been made to develop a software on the basis of empirical correlations amongst the pulse parameters and algorithms in reference to the factor ϕ as reported earlier [17-18] which is capable to select the pulse parameters for a given weld quality. The possibility of working with this user friendly software by applying it to different GMAW commercial power sources for preparation of sound weld of aluminium alloy of desired quality has been analysed. In this work regarding weld quality the software has considered the porosity content of weld deposit and to select the factor f its correlation with porosity as reported [22] earlier has been used.

2. THEORETICAL BACKGROUND

It is largely established [11-20, 22-24] that the primary characteristics of weld deposit, including its geometry, dilution and porosity content, can be satisfactorily correlated to the factor ϕ. But, for a given f there exists infinite number of theoretical solutions of combination of pulse parameters, but all of them may not work with acceptable arc stability using a pulsed current GMAW power source. However, this problem is satisfactorily addressed by prescribing a function of pulse parameters having a solution of the order of unity. Satisfying this condition gives rise to specific solution of pulse parameters conforming arc stability. Considering the algorithms giving correlation amongst the pulse parameters and the factor ϕ it was possible to develope a software based on MATHCAD-7. The operating flow chart of the software is presented in Fig. 1. The software is capable to work for a quick computerised users friendly solution of pulse parameters giving desired ϕ, where the power source can operate satisfactorily to produce desired quality of weld.

3. OPERATION OF POWER SOURCE BY SOFTWARE GUIDED PULSE PARAMETERS

3.1 Nature of Variation of Estimated Pulse Parameters

The computerised solution regarding nature of variation of various pulse parameters with a change in ϕ at different mean currents of 150, 200, 250 and 300A that obtained with the help of the software for smooth welding with stable arc has been shown in Fig. 2 (a-d) respectively. The figure shows that to maintain a stable arc at any I_m the increase in ϕ primarily requires a reduction in t_p and an enhancement in both the I_b and I_p especially at the I_m beyond 200 A. However, it is noticed that at a given ϕ with the increase of I_m from 150 to 200A the power source operates by reduction of f and enhancement in t_p followed by their significant increase and decrease respectively with a further increase of I_m. Whereas, the increase of I_m has always been found to enhance the I_b and I_p. It is also marked that the influence of I_m on the f and t_p also largely depends upon ϕ. At a comparatively low and higher ϕ of 0.1 and 0.4 respectively the nature of variation in f and t_p with I_m has been clearly shown in Fig. 3. At a given ϕ the different behaviour of the variation in f and t_p with I_m across a critical value of about 200A may be primarily correlated to the transition current of the 1.6mm diameter Al-Mg filler wire with respect to the behaviour of metal transfer from the drop to spray mode. This aspect may be studied further for a more detail understanding, which is beyond the scope of the current studies.

3.2 Response of Power Source to Software Solutions

The logical base of the software has been tried for estimation of pulse parameters producing a GMA weld deposit having less than 1% porosity within a given range of ϕ of 0.022-0.177 as prescribed earlier [22]. The solution of the software regarding base current (I_b), pulse current (I_p), pulse time (t_p) and pulse frequency (f) at a randomly selected mean current (I_m), has been used to run pulsed current GMA welding, where the arc voltage was left free to vary for balancing energy distribution in the process. The response of a commercial power source (Esab ARISTO LUG 500) to the pulse parameters determined by the software was studied through bead on plate weld deposition of Al-4.5Mg-Mn (5184) filler wire on 10 mm thick rolled plates of Al-4.5Zn-1Mg (F35 T6) alloy. Prior to welding the plates were mechanically cleaned by stainless steel wire brushing followed by wiping with acetone. The welding was carried out by using 1.6 mm diameter filler wire with about 15 mm electrode extension under argon gas shielding at a flow rate of 18 l/min. All the pulse parameters (I_p, I_b, t_p and f) except I_m were fed in advance to the power source and a pre-approximated wire feed speed was fine tuned during welding to arrive at smooth welding with satisfactory arc stability. During weld deposition the actual machine parameters including I_m have been noted from the power source, where the I_m being a function of wire feed speed acted as an indicator to show how the operating pulse parameters confirms the estimated pulse parameters. During welding the behaviours of the current and voltage of the pulsed current process were also recorded by a transient recorder suitably connected to the electrical circuit of the welding set up. The arc voltage and I_m was estimated as a mean value of the recorded voltage and current plots of the pulse behaviour. It is observed that the machine reading of I_m is quite well in agreement to the calculated one with a maximum variation of the order of 4% and it works satisfactorily with other calculated pulse parameters, as shown in Table – I, in producing stable arc with smooth weld deposition. Thus, it may be inferred that the estimation of pulse parameters for a given ϕ, through the proposed software, is very much acceptable by the power source in practice.

For further verification of the versatility of using the software solution of pulse parameters (Table – I) under certain variation of arc voltage, which often occurs in general practice of deposition due to non-intentional variation in procedural aspects of welding and main power supply, some more bead on plate depositions have been carried out using the same experimental set up as stated above. The measured values of the pulse parameters are typically shown in Table – II. A comparison of the Tables – I and II depicts that the power source is operating with appreciable arc stability under a variation of arc voltage of the order of 3-5 V and the nature of variation in measured values of the pulse parameters with f and I_m is in agreement to that presented in Fig. 2. Thus, it further conforms the versatility of the software to estimate the pulse parameters for smooth operation of a power source at a desired ϕ.

3.3 *Software Guided Welding for Desired Quality*

Under the same conditions of welding process and procedure on the experimental set up as stated above similar bead on plate weld deposition was also carried out on 10mm thick Al-3Mg AW 5754 rolled plate using another (REHM Megapulse 500) commercial power source and 1.6 mm diameter Al-4.5MgMn filler wire at electrode extension of 15mm with argon shielding at a flow rate of 18 l/min. The weld deposition was performed satisfactorily by operating the power source using complete solutions of the software including the wire feed speed for 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 ± 4A. On this filler wire the wire feed rate (W_F) for a given mean current (I_m) was estimated by using the empirically established correlation as follows.

$$I_m = 0.031\ W_F + 0.1001 \qquad \text{------ (i)}$$

The welding has been carried out at the above mentioned range of f anticipating that the weld deposits will not be having porosity more than 2.0 Vol.% as it is observed in case of deposition on Al-Zn-Mg plate [22], rather may be lesser than that due to current deposition on Al-Mg plate. This is because unlike that may happen in case of Al-Zn-Mg plate there is no possibility of any influence of zinc vapour on porosity formation in weld metal deposited on Al-Mg plate. Thus, the porosity formation in weld deposit on Al-Mg plate may be primarily considered as the influence of the pulse parameters and it gives opportunity to exclusively verify the role of software in preparation of pulsed current weld of desired quality. The solutions of the software were found to work quite satisfactorily to give stable arc with practically smooth weld deposition. During welding the actual parameters noted from the power source are given in Table –III, which are found well in agreement to the solutions (Fig. 2) of the software.

The porosity content of weld metal deposited by using all the welding parameters stated in Table – I-III has been measured on metallographic polished transverse section of the bead on plate deposits with the help of an image analyser software and by applying point counting method under optical microscope at a magnification of X100 conforming the ASTM specifications E 1245. The measurements have been carried out by considering all the dark spots of the polished matrix as porosity on it. The porosity content of weld metal deposited on different base material at various welding parameters in reference to Table – I-III has been analysed in different ranges of f as presented in Table - IV. At a comparatively low and high f of 0.059 and 0.43 the porosity content of Al-Mg weld deposit on similar base material has been typically shown in Fig. 4 (a) and (b) respectively. The table shows that the weld deposits are having porosity well within the prescribed limit of 2 Vol.%, which amply justifies the ability of the software to guide the selection of pulse parameters for producing weld of desired quality.

5. CONCLUSIONS

In pulsed current GMAW the pulse parameters hold definite correlations amongst themselves. Software based on algorithms in this regard can select the pulse parameters for an acceptable weld quality. At a given summarized influence of pulse parameters, defined by a dimensionless factor ϕ, the operation of commercial power source using the software based selection of pulse parameters gives stable arc with satisfactory GMA weld deposition of Al-Mg alloy within desired limit of porosity content. To maintain a stable arc at a given f an increase in mean current up to about 200 A requires lowering of pulse frequency followed by an increase in it with a further increase of mean current. The comprehensive understanding over the characteristics of the variation in pulse parameters and their control with the help of software may provide ease and confidence in more wide use of pulsed current GMAW to produce weld of desired quality.

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TABLE -I

The response of power source to the estimated welding parameters during deposition of weld bead on Al-Zn-Mg plate using A-Mg filler wire

Factor ϕ	Wire feed speed (m/min)	Calculated I_m (A)	Measured I_m (A)	Arc voltage (V)	I_b (A)	I_p (A)	t_b (ms)	t_p (ms)	f (Hz)
0.022	10.4	320	327	28	142	332	1.55	28.75	33
0.141	8.2	250	259	26	124	327	4.65	7.85	80
0.156	4.8	150	145	22	71	229	6.3	6.2	80
0.168	7.2	220	219	24	113	315	2.35	2.65	200
0.176	5.7	180	180	23	93	280	2.65	2.35	200
0.177	6.4	200	199	24	104	301	2.05	1.95	250

TABLE - II

Typical reproducibility of using pre-established welding parameters under variation of arc voltage in general practice of weld bead deposition on Al-Zn-Mg alloy

Factor ϕ	Wire feed speed (m/min)	I_m (A)	Arc voltage (V)	I_b (A)	I_p (A)	t_b (ms)	t_p (ms)	f (Hz)
0.022	10.4	327	29	142	332	1.55	28.75	33
0.022	10.4	327	32	142	332	1.55	28.75	33
0.141	8.2	259	30	124	327	4.65	7.85	80
0.141	8.2	259	31	124	327	4.65	7.85	80
0.156	4.8	150	25	71	229	6.3	6.2	80
0.156	4.8	149	26	71	229	6.3	6.2	80
0.168	7.2	219	25	113	315	2.35	2.65	200
0.168	7.2	219	26	113	315	2.35	2.65	200
0.176	5.7	180	27	93	280	2.65	2.35	200
0.176	5.7	180	28	93	280	2.65	2.35	200
0.177	6.4	199	27	104	301	2.05	1.95	250
0.177	6.4	199	28	104	301	2.05	1.95	250

TABLE -III

The behaviour of the measured values of power source in different ranges of f and I_m during operation at estimated welding parameters

ϕ Meas	I_m (A)		I_b (A)		I_p (A)		t_b (ms)		t_p (ms)		Arc voltage (V)	f (Hz)
	Cal	Meas	Cal	Meas	Cal	Meas	Cal	Meas	Cal	Meas		
0.053	149	159	29	33	230	240	6.0	5.9	9.1	9.1	21	66
0.1	149	159	49	53	282	296	9.4	9.1	7.2	7.0	20	60
0.198	161	160	86	92	311	328	10.2	10.0	4.0	4.2	21	70
0.248	150	161	101	107	311	327	10.5	10.4	3.2	3.3	22	73
0.430	149	168	139	145	293	310	12.7	12.6	1.0	0.98	21	73
0.062	205	220	50	54	300	315	12.0	12.2	21.0	21.1	20	30
0.112	202	215	74	80	353	368	16.3	16.0	15.0	14.9	22	32
0.204	208	213	117	122	394	410	17.3	17.1	7.7	7.6	22	40
0.254	208	212	135	144	399	417	14.2	14.1	4.6	4.6	23	53
0.429	195	212	184	191	391	411	14.9	14.8	1.25	1.2	21	62
0.059	248	258	66	72	318	332	3.9	3.8	10.0	9.9	20	72
0.108	248	263	90	98	371	387	6.7	6.6	8.9	8.8	25	64
0.190	242	254	135	141	425	444	7.9	7.6	5.4	5.7	23	75
0.238	248	265	155	161	439	456	8.4	8.2	4.2	4.1	26	79
0.385	253	262	210	220	452	473	9.3	9.6	2.06	1.8	23	88

Cal : Calculated Meas : Measured

Table - IV

Porosity content of weld deposit on different base material at various ϕ

Welding parameters	Base material	Porosity content at various f				
		ϕ	0.022-0.141	0.168-0.177	0.19-0.25	0.38-0.43
Table -I	Al-Zn-Mg	Porosity	0.35 ± 0.19	0.6 ± 0.37	-	-
Table -II		(Vol. %)	0.30 ± 0.07	0.54 ± 0.15		
Table - III	Al-Mg		0.4 ± 0.15	-	0.56 ± 0.2	1.09 ± 0.3

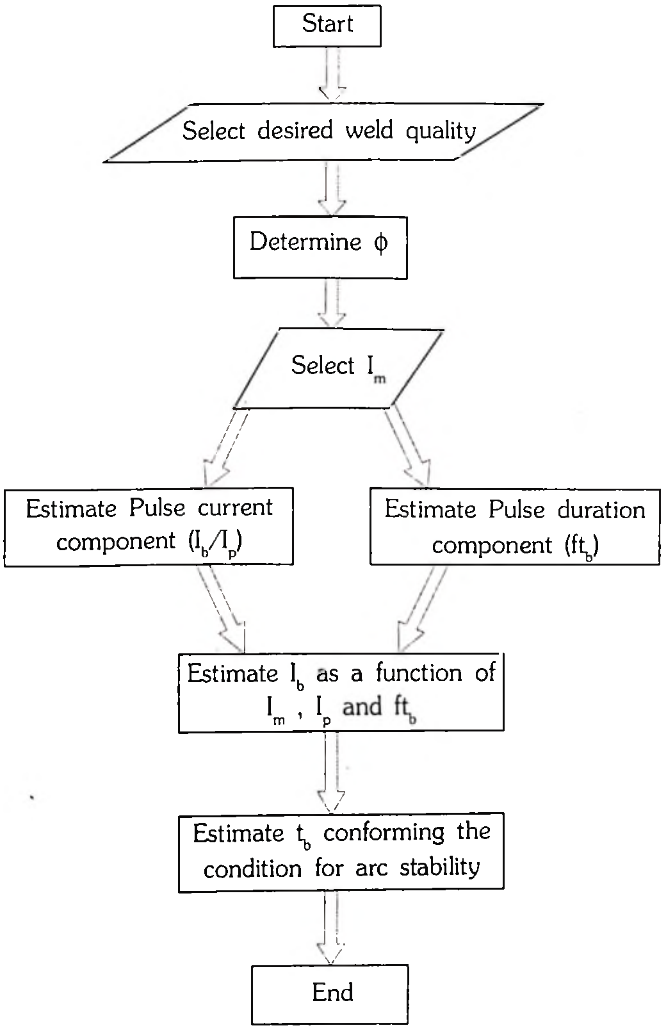


Fig.1 Operating flow chart of the software.

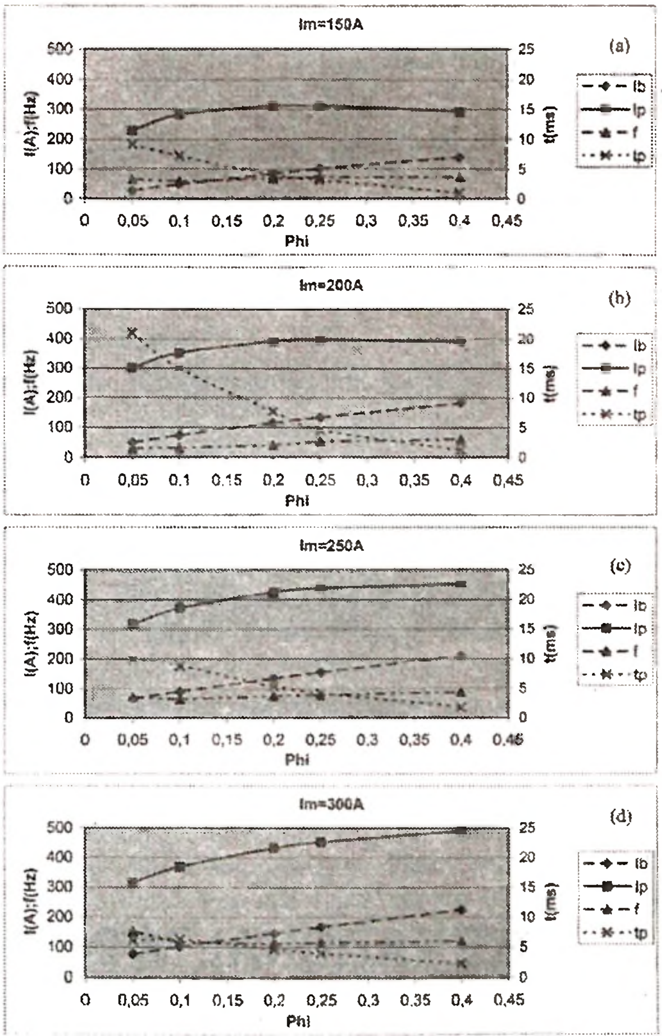


Fig. 2 Computerised solution on nature of variation of various pulse parameters with a change in f giving smooth stable arc at different mean currents of (a) 150, (b) 200, (c) 250 and (d) 300A.

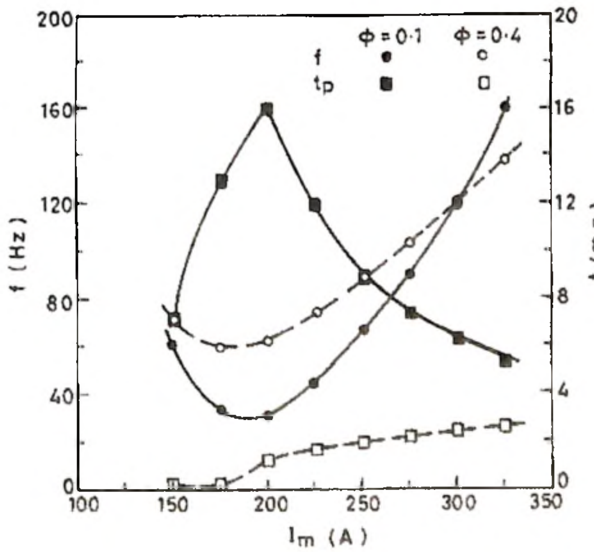
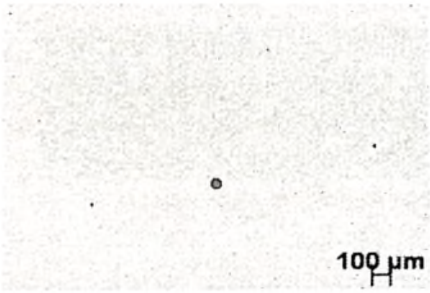


Fig. 3 At a given ϕ of 0.1 and 0.4 the nature of variation in f and t_p with a change of I_m.



(a)

(b)

Fig. 4 At different ϕ of (a) 0.059 and (b) 0.43 typical porosity content of Al-Mg weld deposit on similar base material.

LIST OF FIGURES

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