Arc Stability of Pulse Current Gas Metal Arc Welding of Low Alloy Steel under Different Pulse Parameters and Shielding Gas Compositions

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ABSTRACT

The arc stability and performance of pulse current gas metal arc welding (P-GMAW) process under different pulse parameters (considered as their summarized influence defined by a factor Φ) and shielding gas compositions have been studied through an analysis of irregularity in pulse waveform during weld deposition of low alloy steel. The arc stability has been primarily analysed as average number of peaks (N_{PA}) shooting above an arbitrarily defined current (I_S) at a given interval of arcing, average deviated current (I_{DC}) defined as summation of shooting peak current (I_{SP}) beyond the I_S per peak of instability, average time interval of deviated current (T_{IDC}) and average duration of deviated current (T_{DDC}). The performance of the P-GMAW process has been analyzed with respect to its response to short circuiting. The effect of pulse parameters has been analyzed as a function of Φ, I_m and arc voltage and the shielding gas compositions has been studied with varying content of CO_2 in Ar. It is observed that the arc stability and performance of the P-GMAW power source significantly vary with the change of pulse parameters and CO_2 content of argon gas shielding. A relatively higher Φ, I_m and arc voltage and low CO_2 content of Ar gas shielding provides better arc stability with low short circuiting.

Key Words: P-GMAW, Arc stability, Shielding gas, Pulse parameters and Low alloy steel.

INTRODUCTION

Pulse current gas metal arc welding (P-GMAW) is a highly efficient process for continuous production primarily due to relatively smooth controlled metal transfer under pulse current [1-3] and hence widly employed in welding of thin to thick sections of ferrous and non ferrous materials [4-6]. However, during weldiing it often induces appreciable amount of short circuiting causing irregular transfer of considerably large amount of liquid mass and heat from the electrode to the weld pool, which interrupts gaseous shield of welding arc and consequently affects the weld quality depending upon overall performance of the power source. In general, such a distrubance of welding arc largely studied by measuring the mean value and standard deviation of welding current and arc voltage [7-9]. The interruption of welding arc largely reflects in irregular behaviour of pulse waveform. The pulse waveform are investigated by number of workers [10,11] in alternative current gas-tungsten arc welding (AC-GTAW) process, but hardly any knowledge of these aspects is readily available for comparatively complicated P-GMAW process. Thus, it is interesting to study the arc stability on the basis of interruption of pulse waveform under different pulse parameters and shielding environment in P-GMAW in order to control quality of weld.

The situation to understand the influence of pulse parameters on the above aspects is quite complex due to involvement of relatively large number of simultaneously interactive pulse parameters, such as mean current (I_m), pulse current (I_p), base current (I_b), pulse time (t_p) and pulse frequency (f) as well as arc voltage (V), of the process in governing the characteristics of welding arc and metal transfer. However, a solution to critical control of pulse parameters for a desired operation of P-GMAW process has been well addressed by considering a summarized influence of pulse parameters defined by a

$$\phi = \left(\frac{I_b}{I_p}\right) \times f.t_b$$

derived on the basis of energy balance concept of the process. It is a function of energy term (I_b/I_p) and distribution term ($f.t_b$) in the process [12- 17] where,

$$t_b = \left(\frac{1}{f}\right) - t_p$$

In view of this, an effort has been made in this work to study the effect of pulse parameters and shielding gas compositions on arc stability of P-GMAW process through an analysis of irregularities of pulse waveform as a function of Φ, I_m and arc voltage during deposition of weld bead using low alloy steel filler wire. The observations may be beneficial for better control of the P-GMAW process to produce desired weld quality and also may form a basis of improvement in automation of this welding process.

EXPERIMENTAL

Welding

Arc stability of pulse current gas metal arc welding was studied during bead on plate weld deposition carried out by employing 1.2 mm diameter mild steel filler wire of specification AWS/SFA 5.18ER-70S-6 under Ar+2%CO_2 and Ar+18%CO_2 gas shielding at a flow rate of 18 l/min, where the distance between the nozzle to work piece was maintained at 12mm. Some widely varied pulse parameters giving different Φ at various arc voltage and mean current (I_m), which are used under the above mentioned shielding environments are typically given in Table 1. In order to compare the behaviour of pulse waveform under different shielding environments the studies were carried out by keeping the welding parameters practically similar with respect to the wire feed speed, mean current and arc voltage.

Recording of Pulse Waveform

The pulse behaviour under both the Ar+2%CO_2 and Ar+18%CO_2 gas shielding was thoroughly studied with the help of a transient recorder having a maximum resolution of 1MHz fitted with the electrical circuit of the welding set up for online simultaneous recording of pulse characteristics during welding. The output of the transient recorder is in volts, and hence, both the current and voltage waveforms of the power source are displayed on the monitor of the recorder in volts (V) in the 'Y' axis and duration in millisecond (ms) in 'X' axis. But, in consideration of the current waveform largely affecting the arc stability, it is thoroughly analyzed to achieve the objective of this work. The nature of current waveform with the illustration of the axes as it was recorded during welding has been typically displayed in this report as a signature of arc stability to provide a general impression of the studies. However, the instability in recorded current waveform (in volts) has been analyzed and reported after its conversion to obtain the actual pulse current by using a factor 0.1V= 10A. The instability of pulse waveform is arbitrarily defined by its deviation through shooting beyond a current (I_S) defined as 30A more than I_p. The extent of instability is estimated by counting the average number of peaks (N_{PA}) shooting above the I_S at a given interval of arcing of 200ms. The characteristics of the shooting peaks have been analyzed with respect to their extent of deviation from I_S and the interval and duration of such peaks. The average deviated current (I_{DC}) defined as summation of shooting peak current (I_{SP}) beyond the I_S per peak of instability, average time interval of deviated current (T_{IDC}) and average duration of deviated current (T_{DDC}), as schematically shown in Fig. 1. The numerical expressions for estimation of the above mentioned aspects of pulse current are stated below.

$$I_S = I_P + 30 \quad (1)$$

$$I_{DC} = \frac{\sum_{i=1}^{N_{PA}} I_{SP}}{N_{PA}} \quad (2)$$

$$T_{IDC} = T_{NP2} - T_{NP1} \quad (3)$$

Where, T_{NP1} and T_{NP2} are starting time corresponding to the peaks of N_{PA1} and N_{PA2} respectively.

The behaviour of pulse waveform has been studied at the interval of 200ms at 9-15 locations on the relevant plots obtained through the transient recorder at each welding parameter and the data was statistically analyzed. Validity of the observations on instability of pulse waveform with the change in pulse parameters under different gas shielding has been confirmed by the corresponding high speed video-graphs of the arc environment shoot with the help of a camera operated at a speed 10^4 frames per second. The camera was placed on a rigid fixture in front of the arc along the line of welding and viewed through a lens filter Grade-5 as normal shield glass of welding mask.

RESULTS AND DISCUSSION

The pulse current gas metal arc welding

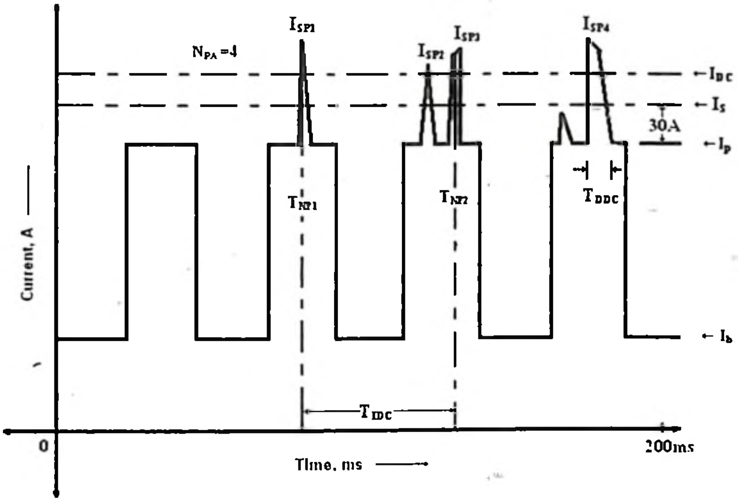
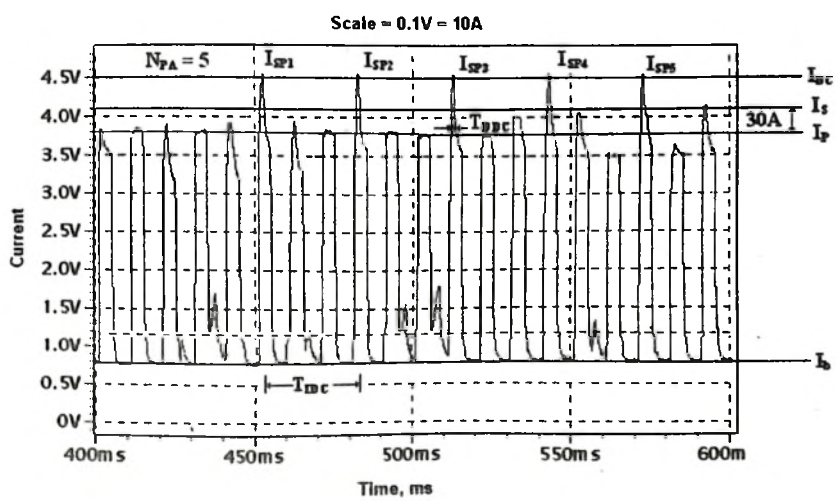
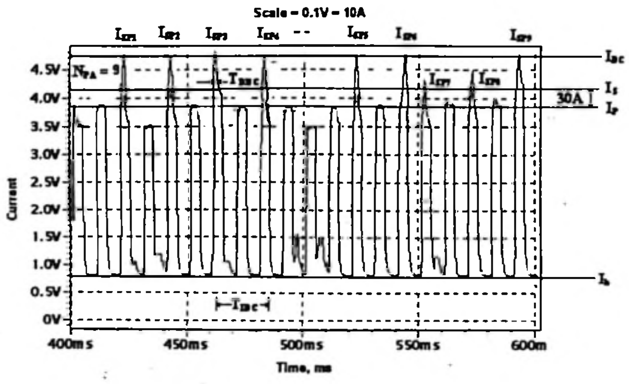


Fig. 1 : Schematic diagram showing different aspects of instability in pulse waveform.

(P-GMAW) usually employs the simplest sinusoidal, practically square pulse, waveform containing only four basic variables as peak current (I_P), base current (I_b), pulse on period (t_p) and pulse off period (t_b). During welding at a given set of pulse parameters, a significant change in I_P and I_b adversely affecting the process performance is generally considered in terms of instability of pulse waveform. The instability of pulse waveform in P-GMAW primarily happens due to short circuiting of electrode to the weld pool which largely depends upon pulse parameters and the type of shielding gas [18-20]. The nature of instability defined by its N_{PA}, I_{DC}, T_{IDC}, and T_{DDC}, primarily diagnose the irregularities of pulse waveform (Fig. 1) influencing the weld quality. Thus, it is interesting to study the behaviour of pulse waveform under different pulse parameters and shielding environment of P-GMAW process. However, the instability of pulse waveform of P-GMAW process under any shielding gas are generally considered in its two primary phases as the pulse on and pulse off periods where, the process mechanisms contributing to the instability of pulse waveform are of different nature. In case of pulse on time the instability of pulse wave form is primarily dictated by the behaviour of metal transfer to the weld pool whereas, during pulse off time it is largely governed by the inertia of droplet influencing the weld quality. In consideration of these facts the behaviour of pulse waveform under different compositions of gas shielding has been studied with respect to variation of pulse parameters in terms of the factor Φ, mean current (I_m) and arc voltage (V). Under the Ar+2%CO_2 gas shielding, the waveforms are analysed by classifying the I_m into three different ranges of about 160±2, 204±1 and 232±2A at the arc voltage of the order of 24±1V whereas, in case of Ar+18%CO_2 gas shielding they are analysed into two levels of I_m of about 179±0.5 and 230±3A at the arc voltages of the order of 24, 30 and 33±1V. Typical nature of instability in pulse current waveform observed during welding at a given close range of Φ, I_m and arc voltage of 0.10±0.01, 230±3A and 24±1V respectively under different gas shielding of Ar+2%CO_2 and Ar+18%CO_2 has been shown in Fig. 2 (a) and (b) respectively.



(a)



(b)

Fig. 2 : Typical nature of instability in pulse waveform observed during welding at a given Φ, I_m and arc voltage of 0.10, 230A and 24V respectively under different gas shielding of (a) Ar+2%CO_2 and (b) Ar+18%CO_2.

The average deviated current (I_{DC}) shooting above the I_S as measured under the same range of Φ and I_m has also been found to follow a similar trend to that observed in case of N_{PA} (Fig. 3), as shown in Fig. 4. This may be primarily attributed to the variation in peak current I_P, as depicted in Table 1. In this regard, it is further noted that the average time interval of deviated current (T_{IDC}) and average duration of deviated current (T_{DDC}) at a given duration of arc operation of 200ms are also well correlated to the factor Φ and I_m. The effect of Φ under varied I_m in the range of 160-230A on the T_{IDC} and T_{DDC} has been

Under Ar+2%CO_2 Gas Shielding

At a given arc voltage of 24±1V the influence of Φ on the N_{PA} has been shown in Fig. 3 where the I_m is varied to the said levels lying in a range of about 160-232A. The figure shows that at a given arc voltage the N_{PA} enhances significantly with the increase of Φ irrespective of variation in I_m at relatively low and high levels as stated above. However, the figure also depicts that at a given Φ and arc voltage, the increase of I_m enhances the N_{PA} appreciably. Such a variation in N_{PA} as a function of Φ and I_m may have primarily happened due to considerable increase in velocity of droplets (V_t) and number of droplets [15] transfer per pulse along with a decrease of arc length [16] with the increase of Φ and I_m. This is because it may lead to short circuiting of metal transfer to weld pool resulting in to a sharp shooting of peaks as typically observed on the recorded pulse wave form (Fig. 2(a)). In addition to that, the increase of I_p with the increase of Φ and I_m also enhances the joules heating [21], which may also play an important role for variation of N_{PA}.

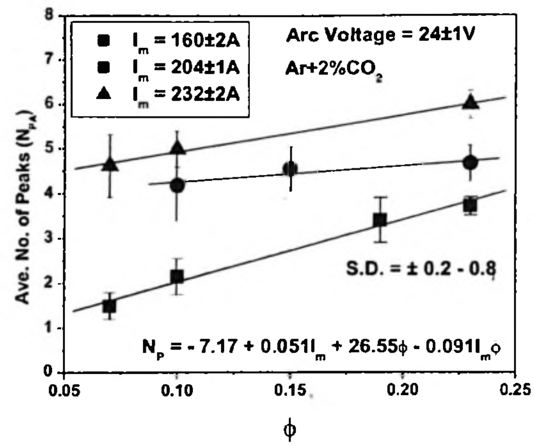


Fig. 3 : Under Ar+2%CO_2 gas shielding at different I_m, the effect of Φ on average number of peaks shooting per 200ms above 30A from the given average peak current.

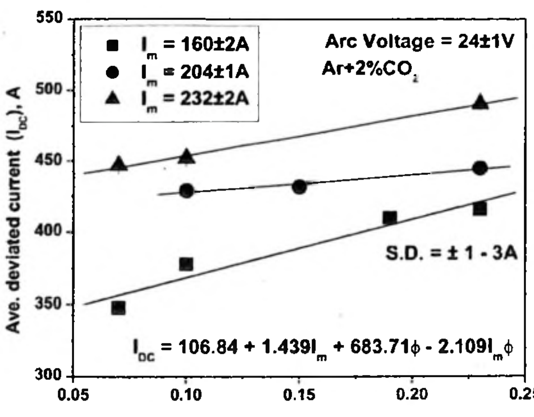


Fig. 4 : Under Ar+2%CO_2 gas shielding at different I_m, the effect of Φ on average deviated current per 200ms above from the given average peak current.

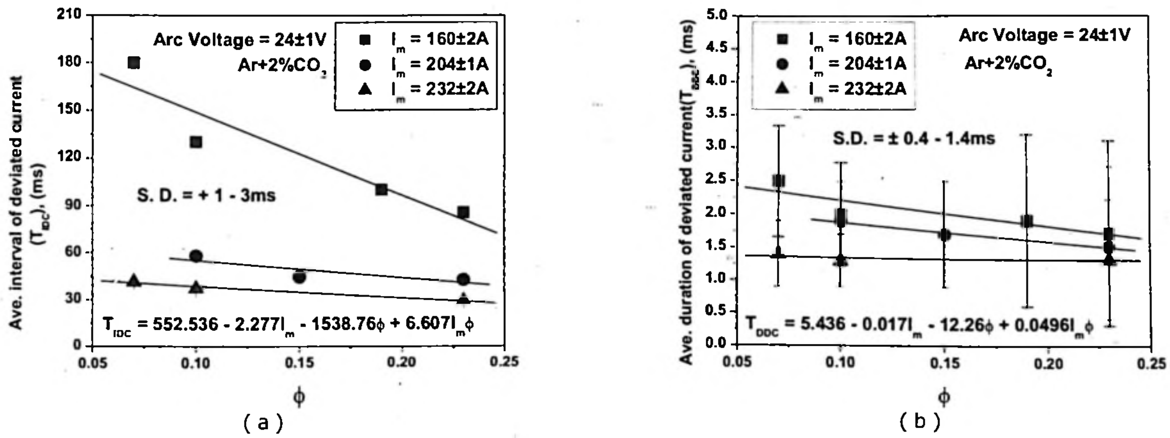


Fig. 5 : Under Ar+2%CO_2 gas shielding at different I_m, the effect of Φ on (a) average interval of deviated current per 200ms and (b) average duration of deviated current per 200ms.

shown in Figs. 5 (a) and (b) respectively. The figures show that at a given I_m the increase of Φ and at a given Φ, the increase of I_m reduces the T_{IDC} and T_{DDC} significantly. The decrease of T_{IDC} and T_{DDC} with the increase of Φ and I_m may have primarily happened due to reduction of duty cycle [$\frac{t_p}{(t_p + t_b)}$] and and duration ratio [$\frac{t_p}{t_b}$], as shown in Table 1.

During pulse on period, the significant change in arc shape due to short circuiting of electrode with the weld pool as observed in consecutive frames of video-graphs captured during welding at different combinations of I_m and Φ respectively of 160A and 0.20 and 230A and 0.07 has been shown in Fig. 6 and Fig. 7 respectively. Such video-graphs have also facilitated the measurement of T_{DDC} of the pulse waveform by considering number of frames showing short circuiting at a given pulse on period. It is observed that the measured T_{DDC} on video-graph (Fig. 6 and Fig. 7) is well in agreement to the T_{DDC} measured with the help of transient recorder plot (Fig. 5(b)).

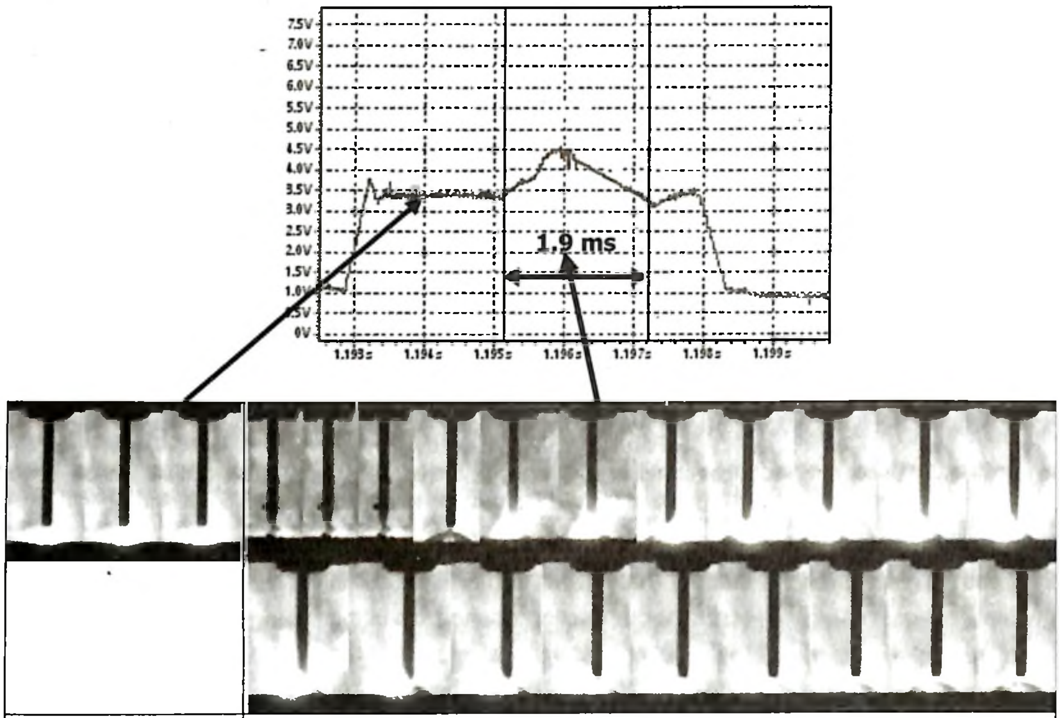
In view of the above discussions the arc stability has been further studied in terms of the fraction of short circuiting (SC, %) of metal transfer also at an interval of 200ms as stated below under different pulse parameters and shielding gas. The understanding of SC as a function of Φ, I_m and arc voltage may highlight overall performance of the power source during welding. The SC per 200ms of pulse current arcing has been estimated as follows.

$$SC = \frac{(N_{PA} \times T_{DDC})}{200} \times 100 \qquad (4)$$

Like N_{PA}, I_{DC}, T_{IDC} and T_{DDC}, the SC also shows good correlation with the factor Φ and I_m as shown in Fig. 8. The figure depicts that at a given arc voltage the SC show insignificant variation with the increase of Φ and I_m, which infers that the use of Ar+2%CO_2 gas shielding provides practically smooth weld bead deposition.

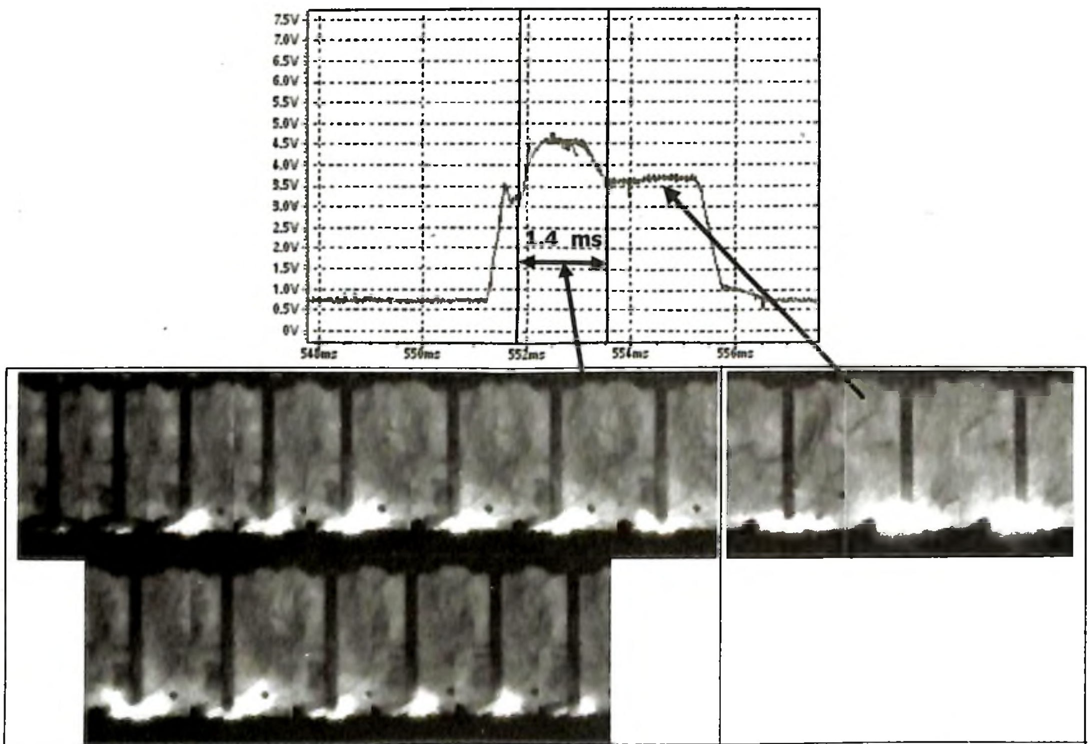
Under Ar+18%CO_2 Gas Shielding

At a given arc voltage and I_m of 24±1V and 230±3A respectively, the effect of Φ on N_{PA} has been shown in Fig. 9. In agreement to the earlier observations, (Fig. 3) here also it is observed that at a given mean current and arc voltage the N_{PA} enhances significantly with the increase of Φ in the range of 0.06 to 0.35. But, a comparison of the Fig. 3 and Fig. 9 reveals that at a given Φ and I_m the Ar+2%CO_2 gas shielding produces comparatively less N_{PA} than that of the Ar+18%CO_2 gas shielding environment within a stipulated period of 200ms of arcing process. This may be primarily attributed to relatively higher spatter generation because of more short circuiting of metal transfer to weld pool due to comparatively higher heat flow associated with the Ar+18%CO_2 shielding resulting from its higher thermal conductivity of 1.247 $Wm^{-1}K^{-1}$ as compared to that of Ar+2%CO_2 as 0.847 $Wm^{-1}K^{-1}$ [15, 21]. In addition to that the increase of CO_2 content in argon gas mixture also reduces the arc length [16], which may also play a significant role for increase in N_{PA}. In consideration to the above observations it may be realised that the use of Ar+18%CO_2 gas shielding produces comparatively more short circuiting and spatter than that happens in case of using Ar+2%CO_2 gas shielding. These observations are in agreement to an earlier study [22, 23] on GMA weld deposition of mild steel



Smooth Arc	Short circuiting in peak current period (19 frames = 1.9 ms)

Fig. 6 : Under Ar+2%CO_2 gas shielding typical sequence of photograph showing short circuit of electrode to weld pool at a given arc voltage, I_m and Φ of 24V, 160A and 0.20 respectively.



Short circuiting in peak current period (14 frames = 1.4 ms)	Smooth arc in peak current period

Fig. 7 : Under Ar+2%CO_2 gas shielding typical sequence of photograph showing short circuit of electrode to weld pool at a given arc voltage, I_m and Φ of 24V, 230A and 0.07 respectively.

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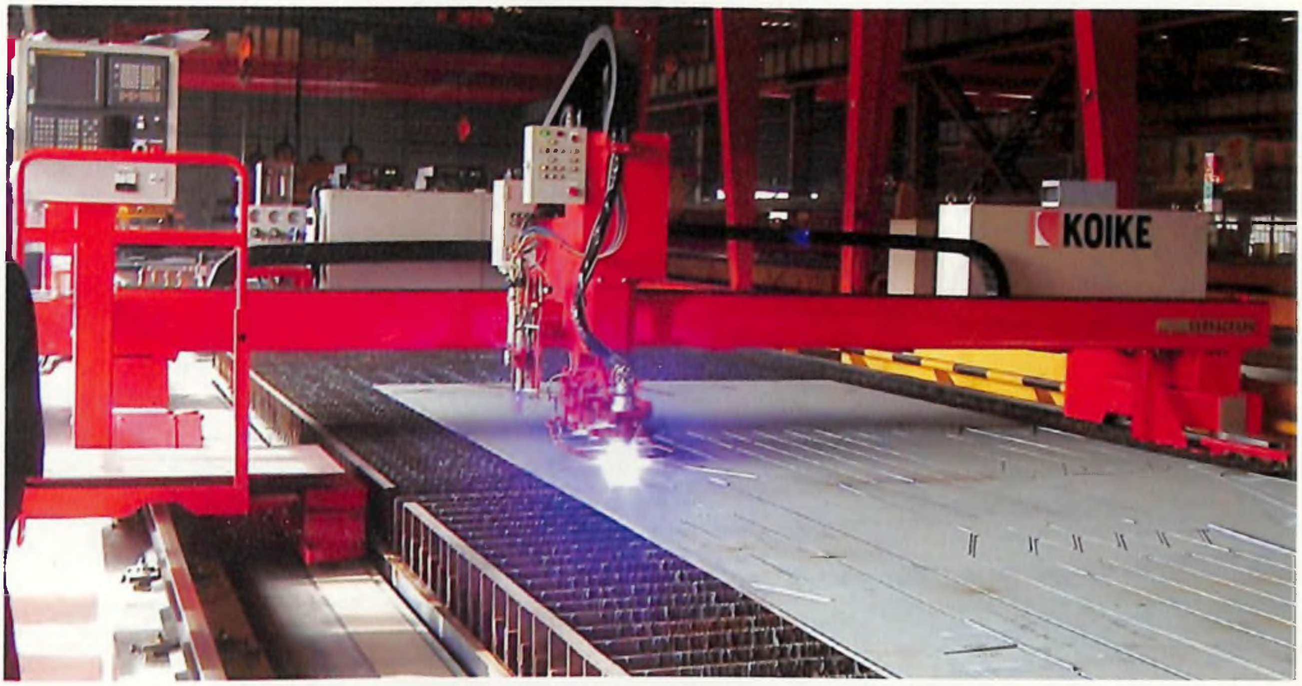

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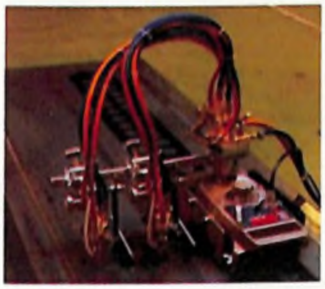

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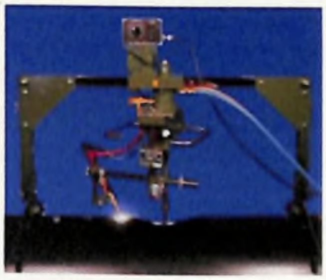

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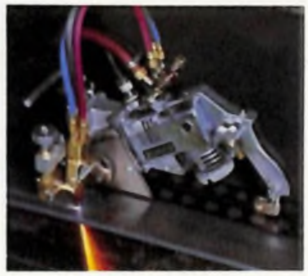

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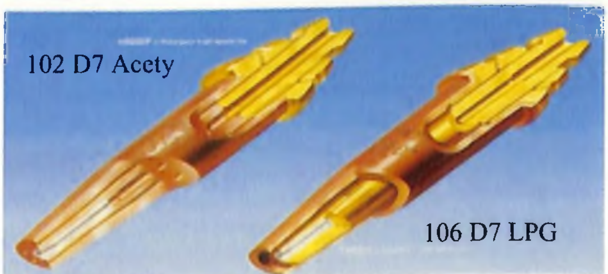

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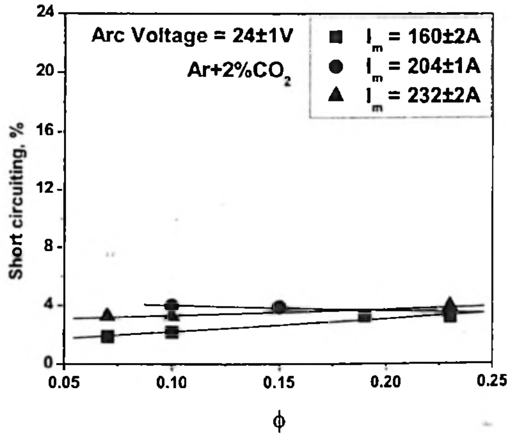


Fig. 8 : Under Ar+2%CO_2 gas shielding at different I_m, the effect of Φ on percentage of short circuiting per 200ms.

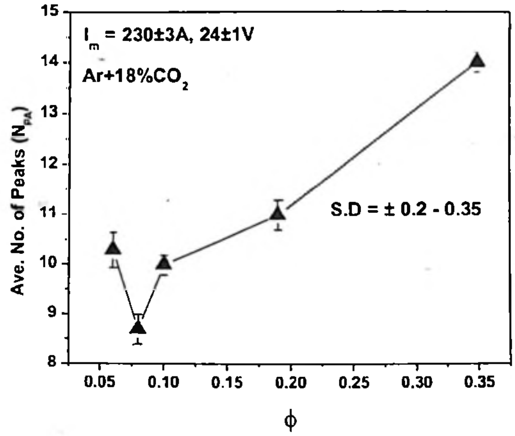


Fig. 9 : Under Ar+18%CO_2 gas shielding at a given mean current (230A) and arc voltage (24V), the effect of Φ on average number of peaks shooting above the average peak current per 200ms.

showing that the increase of CO_2 content in argon gas mixture significantly enhances the short circuiting of metal transfer as well as produces more spatters.

Similar to that followed earlier (Fig. 4) here also the I_{DC} has been estimated in consideration of N_{PA}. At a given arc voltage and I_m of 24±1V and 230±3A respectively, the effect of Φ on I_{DC} has been shown in Fig. 10. The figure shows that at a given mean current and arc voltage the increase of Φ has a practically insignificant influence on I_{DC}, which is in contrast to the earlier observations on Ar+2%CO_2 (Fig. 4). This may have primarily happened due to insignificant variation in peak current I_P (Table 1) with a similar change in Φ as compared to that observed in case of Ar+2%CO_2 shielding.

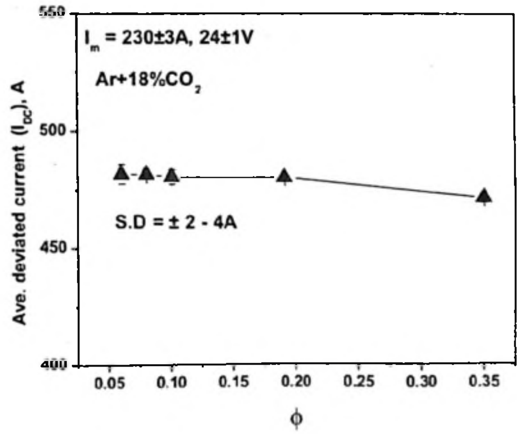


Fig. 10 : Under Ar+18%CO_2 gas shielding at a given mean current (230A) and arc voltage (24V), the effect of Φ on average current deviated above the given average peak current per 200ms.

At a given arc voltage and I_m of 24±1V and 230±3A respectively, the effect of Φ on T_{IDC} and T_{DDC} has been shown in Fig. 11 (a) and (b) respectively. The Fig. 11 (a) shows that with the increase of Φ insignificantly varies the T_{IDC} but, in contrast to the earlier observation made under Ar+2%CO_2 (Fig. 5(b)), the T_{DDC} decreases significantly (Fig. 11 (b)). However, here it is observed that at a given I_m of about 230A and any Φ the T_{IDC} is significantly higher than that found in case of Ar+2%CO_2 gas shielding (Fig. 5(a)). Thus, the observation on T_{IDC} as a function of Φ at I_m higher than transition current [21,23] [215] further confirms that the use of Ar+18%CO_2 gas shielding produces relatively more short circuiting than that happens in case of Ar+2%CO_2 gas shielding.

At a given combination of I_m and Φ respectively of 179±0.5A and 0.19 and 229±2A and 0.35 the effect of arc voltage on N_{PA} has been shown in Fig. 12. It has been observed that at higher I_m (about 229A) beyond the transition current an increase of arc voltage up to 30V considerably reduces the N_{PA} followed by an insignificant change in it with a further increase of arc voltage to 33V. However, at a lower I_m of about 176A the increase of arc voltage up to 30V practically does not affect the N_{PA} followed by a significant increase in it with a further increase of arc voltage to 33V. Such a variation of N_{PA} with respect to arc voltage may have primarily happened because at a given mean current and Φ the increase of arc voltage enhances the arc pressure, and tends to constrict the arc which consequently strengthens the magnetic field at it [21, 24]. In addition to that the spray mode of metal transfer significantly reduces the heat loss [15] which adversly influences the short circuiting.

At the given above mentioned combination of I_m and Φ, the effect of arc voltage on the I_{DC}, T_{IDC} and T_{DDC} has been shown in Figs. 13, 14(a) and 14(b) respectively. The figures show that the increase of arc voltage at any mean current has practically insignificant influence on the I_{DC}, T_{IDC} and T_{DDC} but, at a given arc voltage, the increase of mean current to above transition current relatively reduces the I_{DC} and T_{IDC} and considerably lowers the T_{DDC}. It infers firmly that on setting of spray mode of metal transfer by keeping the I_m beyond transition current reduces instability of the arc at any arc voltage. However, it is noticed that at a given arc voltage and Φ of about 24V and 0.2 respectively, the N_{PA} and T_{DDC} enhances but, the T_{IDC} reduces significantly due to shifting of gas shielding from Ar+2%CO_2 to Ar+18%CO_2 at both the lower and higher I_m than the transition current. Under this condition the average deviated current (I_{DC}) has also been found to increase markedly with the change in gas shielding from Ar+2%CO_2 to Ar+18%CO_2 especially at I_m lower than the transition current.

Such behaviours clearly indicate the possibilities of more short circuiting during pulse current welding under the Ar+18%CO_2 gas shielding. The typical nature of such short circuiting has been shown in Fig. 15 and Fig. 16 where, the arc voltage has been varied to 24 and 33V respectively at a given I_m and Φ of 230A and 0.35 respectively. The figure

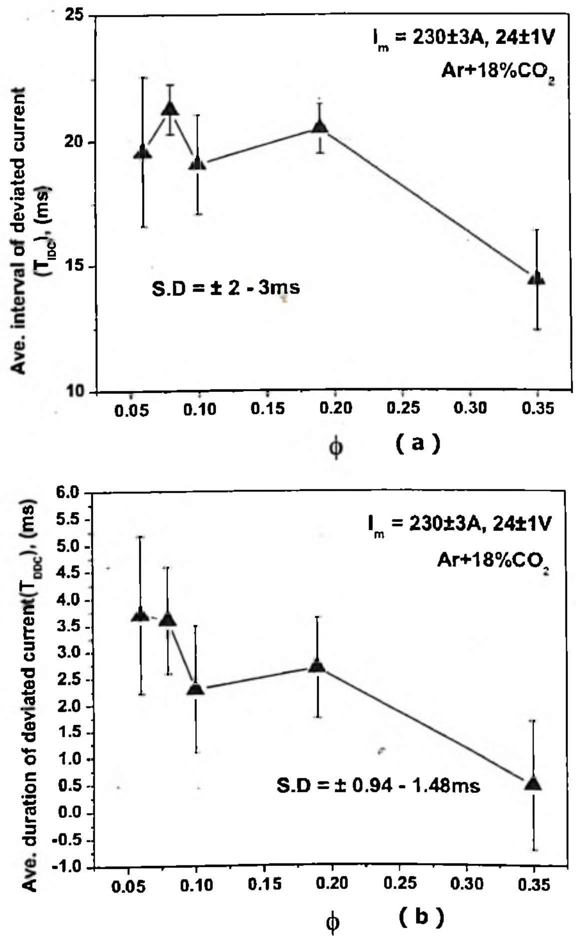


Fig. 11 : Under Ar+18%CO_2 gas shielding at a given mean current (230A) and arc voltage (24V), the effect of Φ on (a) average interval of deviated current per 200ms and (b) average duration of deviated current per 200ms.

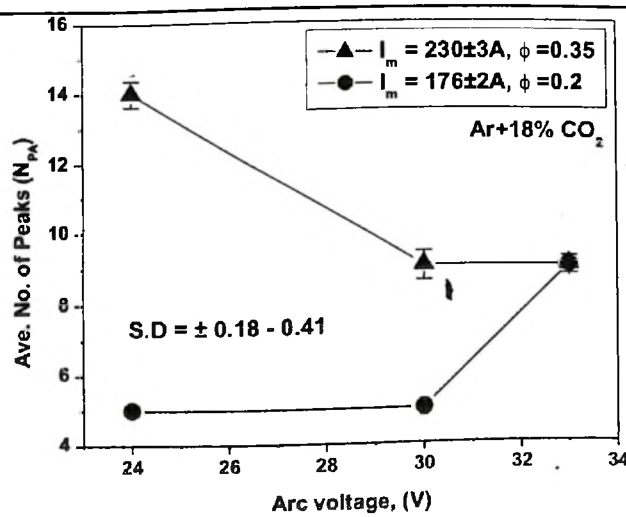


Fig. 12 : Under Ar+18%CO_2 gas shielding at a given combination of relatively higher and lower Φ and I_m of 0.35, 229±2A and 0.19, 179±0.5A respectively, the effect of arc voltage on average number of peaks shooting above the given average peak current per 200ms.

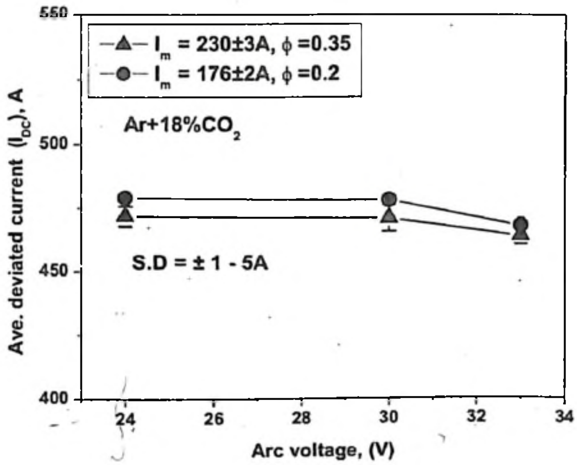
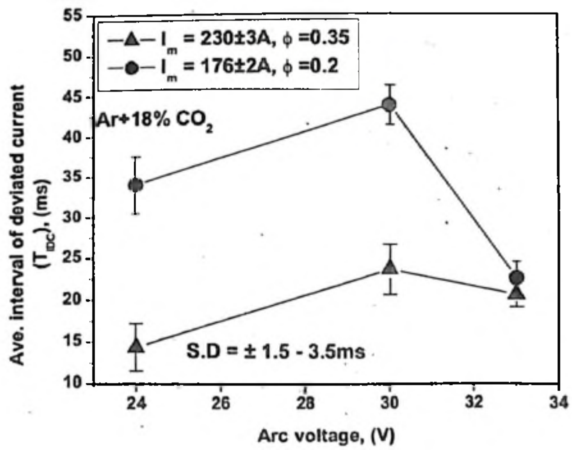
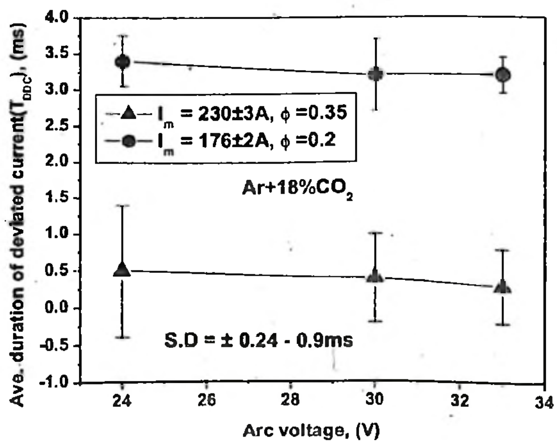


Fig. 13 : Under Ar+18%CO_2 gas shielding at a given combination of relatively higher and lower Φ and I_m of 0.35, 229±2A and 0.19, 179±0.5A respectively, the effect of arc voltage on average current deviated above the given average peak current per 200ms.



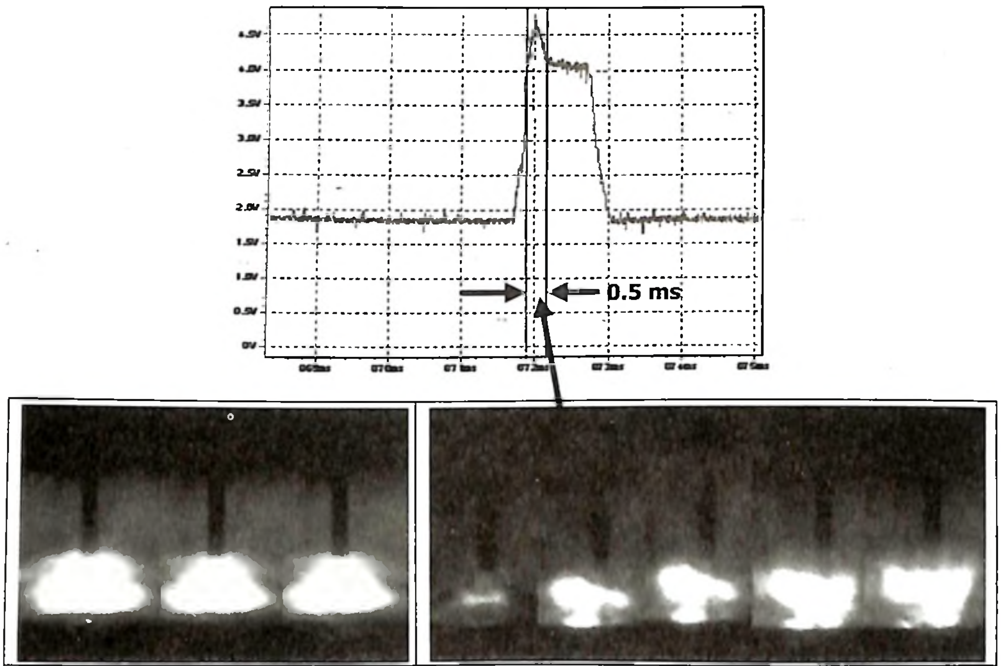
(a)



(b)

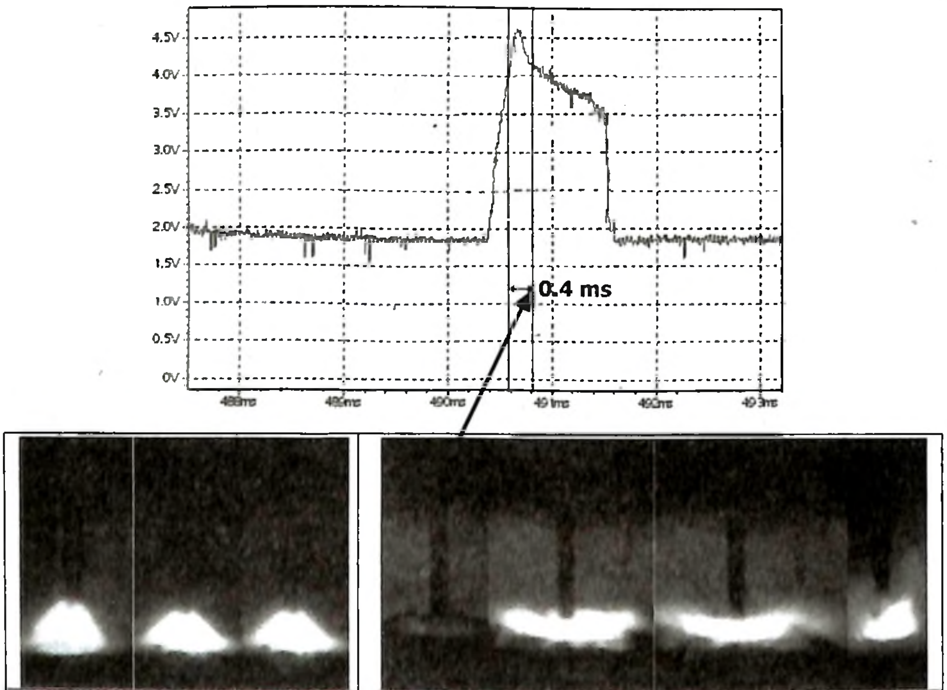
Fig. 14 : Under Ar+18%CO_2 gas shielding at a given combination of relatively higher and lower Φ and I_m of 0.35, 229±2A and 0.19, 179±0.5A respectively, the effect of arc voltage on (a) average interval of deviated current per 200ms and (b) average duration of deviated current per 200ms.

shows that the intensity and duration of short circuiting relatively reduce with the increase of arc voltage. An analytical understanding on the extent of short circuiting as a function of Φ has been shown in Fig. 17 where the arc voltage and I_m has been kept at 24±1V and 230±2A respectively. The figure shows that in general the designing of pulse parameters giving higher Φ considerably reduces the short circuiting (SC). However, with a repetitive result a criticality observed in this regard at a Φ of about 0.1 is not well understood so far. Such a critical behaviour of the process at the Φ of about 0.1 corroborates the reports of earlier workers on criticality of weld characteristics at the similar Φ justifies the necessity of a detail study in this regard. In the context of reducing the short circuiting by keeping relatively higher I_m (230A) beyond transition current and larger Φ (0.35) of pulse current, it is also interestingly noted that under this condition an increase of arc voltage also appreciably helps in reducing the short circuiting as shown in Fig. 18. But the figure also shows that the things are not very much similar at a relatively lower I_m (176A) than the transition current where, at a given Φ of 0.2 the increase of arc voltage from 24 to 30V marginally reduces the short circuiting followed by a considerable increase in it with a further increase of arc voltage to 33V. This may have primarily happened because the relatively soft arc at higher arc voltage discourages the effective spray transfer especially at low I_m.



Smooth arc in peak current period	Short circuiting in peak current period (5 frames = 0.5 ms)

Fig. 15 : Under Ar+18%CO_2 gas shielding typical sequence of photograph showing short circuit of electrode to weld pool at a given I_m , V and Φ of 230A, 24V and 0.35 respectively.



Smooth arc in peak current period	Short circuiting in peak current period (4 frames = 0.4 ms)

Fig. 16 : Under Ar+18%CO_2 gas shielding typical sequence of photograph showing short circuit of electrode to weld pool at a given I_m , V and Φ of 230A, 33V and 0.35 respectively.

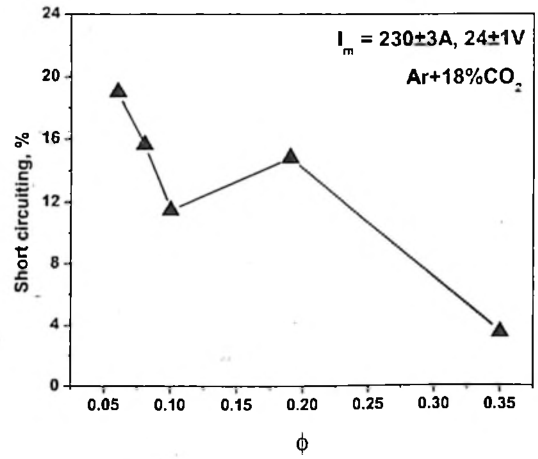


Fig. 17 : Under Ar+18%CO_2 gas shielding at a given mean current and arc voltage of 230A and 24V respectively, the effect of Φ on percentage of short circuiting per 200ms.

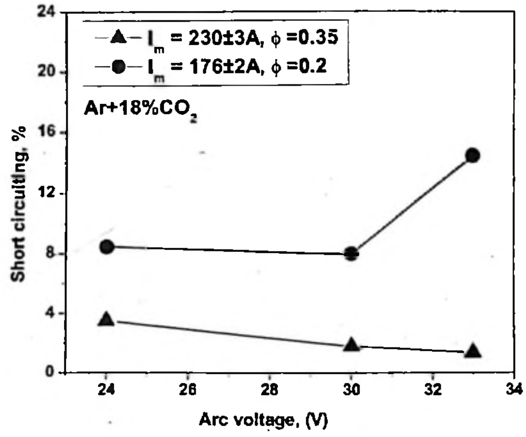


Fig. 18 : Under Ar+18%CO_2 gas shielding at a given combination of relatively higher and lower Φ and I_m of 0.35, 229±2A and 0.19, 179±0.5A respectively, the effect of arc voltage on percentage of short circuiting per 200ms.

CONCLUSIONS

During weld deposition of low alloy steel, the arc stability and performance of the P-GMAW power source with respect to short circuiting significantly vary with the change of pulse parameters and CO_2 content of Ar-CO_2 gas shielding. Under a combination of pulse parameters of a given Φ and I_m, the Ar+2%CO_2 gas shielding provides better arc stability as compared to that observed in case of using Ar+18%CO_2 gas shielding. However, at a given arc voltage and any mean current, the average number of instability in peaks of pulse current enhances with the change in pulse parameters giving rise to a higher value of the factor Φ under Ar+2%CO_2 gas shielding. Whereas, at any arc voltage keeping the I_m beyond transition current improves the arc stability as it is observed even under Ar+18%CO_2 gas shielding. The observations on various critical aspects of arc stability of the P-GMAW process may facilitate more effective application of it in automation.

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Table 1 : Under different shielding gases the pulse parameters of different Φ measured during welding.

Shielding Gas	Wire Feed Speed (m/min)	Φ	I_m (A)	I_p	I_b	f (Hz)	t_b (sec)	t_p (sec)	t_p / t_b	Duty Cycle $(\frac{t_p}{(t_p + t_b)})$	Arc Voltage (V)
Ar+2%CO_2	5	0.07	159	280	40	50	0.01	0.01	1.00	0.50	24
	5	0.11	160	312	60	50	0.012	0.008	0.67	0.40	23
	5	0.20	162	352	96	50	0.015	0.005	0.33	0.25	24
	5	0.23	161	372	108	50	0.016	0.004	0.25	0.20	25
	7	0.11	204	356	76	150	0.0037	0.003	0.81	0.45	24
	7	0.15	205	372	88	100	0.006	0.004	0.67	0.40	24
	7	0.23	205	420	128	50	0.015	0.005	0.33	0.25	25
	8	0.07	233	344	60	100	0.004	0.006	1.50	0.60	24
	8	0.11	234	380	80	100	0.005	0.005	1.00	0.50	25
	8	0.23	231	440	140	100	0.007	0.003	0.43	0.30	25
Ar+18%CO_2	6	0.19	179	408	105	50	0.015	0.005	0.33	0.25	25
	6	0.19	180	408	105	50	0.015	0.005	0.33	0.25	30
	6	0.19	180	408	104	50	0.015	0.005	0.33	0.25	33
	8	0.06	227	394	50.6	100	0.005	0.005	1.00	0.50	25
	8	0.08	230	395	64	100	0.005	0.005	1.00	0.50	24
	8	0.10	232	388	80	100	0.005	0.005	1.00	0.50	25
	8	0.19	230	390	123	100	0.006	0.004	0.67	0.40	24
	8	0.35	227	410	184	200	0.004	0.001	0.25	0.20	24
	8	0.35	231	407	184	200	0.004	0.001	0.25	0.20	30
	8	0.35	227	413	181	200	0.004	0.001	0.25	0.20	33