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Characterization of dynamic behaviour of short circuit in pulsed Gas Metal Arc Welding of aluminum

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Methodology of research

ABSTRACT

Purpose: This paper studies dynamic characteristics of short circuit in the pulsed current gas metal arc welding (GMAW-P).
Design/methodology/approach: Welding experiments with different values of pulsing parameter and simultaneous recording of high speed camera pictures and welding signals (such as current and voltage) were used to identify different short circuit conditions in GMAW-P. The investigation is based on the synchronization of welding signals and high speed camera to characterize different types of short circuit occurring in GMAW-P system. The behaviour of short circuit under the influence of different pulsing conditions is also investigated.
Findings: It will be shown in the paper that short circuit in GMAW-P occurs in different forms which can be categorized depending upon time of short circuit and phase (peak or base time) of the pulse. Further investigation involves study of the dynamic behaviour of short circuit with variation of different pulsing parameters.
Research limitations/implications: The results show that by varying the pulse parameters, behaviour of short circuit in GMAW-P is changed. The pulse parameters can be adjusted to avoid occurrence of short circuit in GMAW-P. Future work should concentrate on development of practical indices in terms of pulse welding parameters for quantitative estimation of short circuit occurrence and avoidance.
Originality/value: Determination of proper working parameters with GMAW-P is crucial for the appropriate selection of pulse welding parameters. As short-circuiting is common between the welding electrode and the workpiece in GMAW-P, so in order to estimate the working parameters and ensure stable GMAW-P understanding dynamic behaviour of short circuit in GMAW-P will be useful. However, in case of aluminum hardly any attempt is made to analyse the dynamic behaviour of short circuit in GMAW-P. This paper analyses the short circuit phenomenon in GMAW-P and their behaviour with varying pulsing parameters.
Keywords: Short circuit; GMAW-P; Aluminum; Pulsing parameters

1. Introduction

Aluminum is characterized by same strength but light weight as compared to steel [10, 19]. Such attribute make aluminum a primary choice for reducing weight in automobile structures as well as other commercial applications. Among the different aluminum welding processes [4, 20], GMAW-P is widely used for welding thin section of aluminum because of low average heat input and periodical metal transfer using pulsing of current between higher and lower values.

GMAW-P has been investigated for long time ever since widespread use of aluminum commercially started. The mode of metal transfer plays a vital role in ensuring good quality aluminum weld. In particular, short circuit can produce significant amount of spatter. The pulsing of current in GMAW-P, however, introduces additional welding parameters like peak and base currents, and peak and base durations. Determination of proper working parameters with GMAW-P is very important and time consuming process [25]. It is therefore evident that detailed process knowledge is crucial to the appropriate selection of pulse welding parameters. As short-circuiting is common between the welding electrode and the workpiece in GMAW-P, so in order to estimate the working parameters and ensure stable GMAW-P understanding dynamic behaviour of short circuit in GMAW-P will be useful.

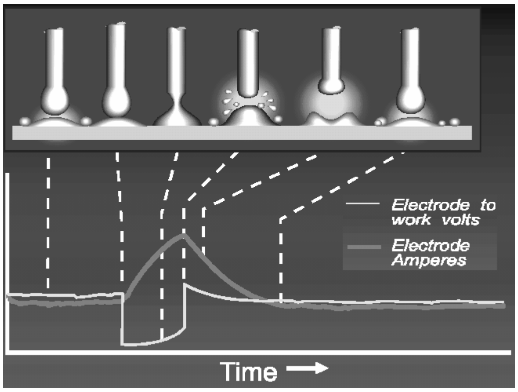


Fig. 1. Short circuit metal transfer phenomenon

Dynamic analysis involves development of model in terms of electrical circuit which combines various aspects of the physical modelling to simulate overall behaviour of the process [5, 11, 21, 24, 26-27]. Experiments have shown that maximum process stability occurs when short circuit frequency equals the oscillation frequency of weld pool [6, 8-9, 13, 16, 18, 22-23]. Statistical analysis assesses the process stability quantitatively by dividing the short circuit process into characteristics phases such as arc time, short circuit time [1, 7, 14-15, 17]. However, in case of aluminum hardly any attempt is made to analyse the dynamic behaviour of short circuit in GMAW-P. This paper analyses the short circuit phenomenon in GMAW-P and their behaviour with varying pulsing parameters.

2. Welding technology

2.1. Short circuit metal transfer

Short circuit metal transfer (as shown in Figure 1) occurs at the lowest range of welding current. It is characterized by periodic contact between the electrode and the weld pool. A short circuit begins with an electric arc formed by the potential difference between the electrode and workpiece. Droplet growth occurs in the arcing period and the arc diminishes when the filler wire makes contact with the weld pool resulting in short circuit. During the contact period, welding voltage decreases to almost zero, current reaches maximum value and metal transfer from the electrode to the workpiece takes place.

2.2. Pulse metal transfer

During the mid 1960's, an alternative transfer technique of GMAW-P was invented. This mode of metal transfer overcomes the drawbacks of globular mode while achieving the benefits of spray transfer. This mode is characterized by pulsing of current between low-level background current and high-level peak current in such a way that mean current is always below the threshold level of spray transfer as shown in Figure 2. The purpose of background current is to maintain arc where as peak currents are long enough to make sure detachment of the molten droplet.

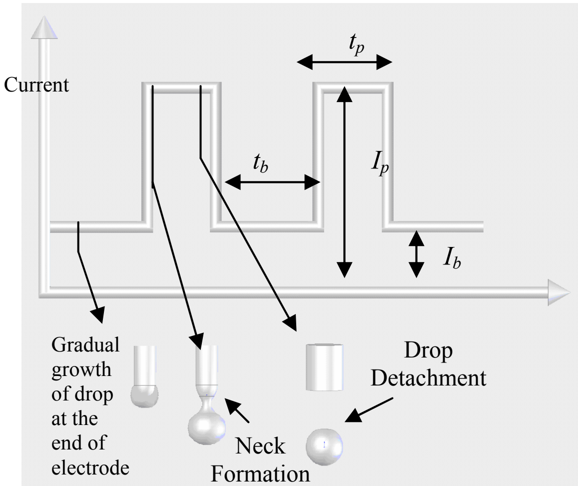


Fig. 2. Pulse metal transfer phenomenon

3. Experiments

3.1. Experimental Setup

The experimental set-up used in this study is shown in Figure 3. It consists of a pulsed type inverter controlled GMAW power source with constant current characteristics, automated welding system with 3-axis servo motors and controllers, sensors for measuring actual welding current and voltage signals, A/D converter, high speed camera with 10000 frames/s performance and xenon lamp along with set of lenses and filters was used as light source to provide back light for high-speed filming.

The welding current was measured with a Hall sensor, which was attached to the earth cable, and the arc voltage also was measured between the output terminals. The measured signal

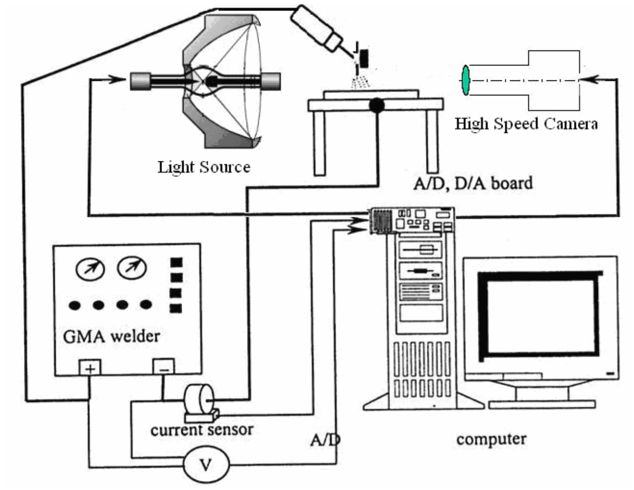


Fig. 3. Schematic diagram of experimental setup

were transferred into the computer via an A/D converter with a maximum sampling rate of 10 kHz. The data sampling rate for the signals was 10000 samples/s. The noise on the signals was removed by a digital low pass filter with a 10 Hz cut-off frequency. The waveform signals were collected during a 2 s period after 10 s elapsed from the start of welding. Experiments were carried out using the principle of back-light high speed xenon lamp cinematography which was synchronized with data acquisition system. In this method, a xenon lamp acts as a backlight and is passed through a set of lenses and filters. In the process, almost all of the arc light is eliminated and a shadow of the drop and wire is captured by a high-speed camera.

3.2. Welding conditions

In the welding experiments, a 4047 aluminum alloy welding wire with a 1.2-mm diameter was used in the experiments. All experiments were carried out with contact tip to work distance (CTWD) of 20mm, using pure argon as shielding gas at a flow rate of 20 L/min. The workpiece was 6061 aluminum alloy with a thickness of 6 mm. The welding speed was set at 4 mm/s and bead –on-plate was performed for total welding time of 2 secs.

Table 1
Experimental design plan

Levels	1	2	3	4
Peak Current (A)	220	250	280	310
Base Current (A)	40	50	60	70
Peak Time (ms)	2	4	6	8
Base Time (ms)	10	16	22	28

Table 1 shows the setting conditions of pulsing parameters used for the experimentation. The threshold voltage and the average voltage were used to distinguish the pulsing region and the short-circuit region from the filtered signals.

4. Results and discussion

4.1. Various Forms of Short Circuit in GMAW-P

Short circuit is a very dynamic process. Major problem occurring during short circuit is unstable process behaviour accompanied by the formation of spatter. When considering short circuit in GMAW-P, we can easily define four types of short circuit behaviour in GMAW-P:

1) Instantaneous Shorts
2) Base Shorts
3) Peak Shorts
4) Butting of Electrode into Work piece

Instantaneous Shorts

In instantaneous shorts, the electrode touches the weld pool for a very short period (< 1 ms in this case) of time, but no metal transfer takes place. Instantaneous shorts were observed more in cases when peak time was longer and base time was shorter, and also when peak and base current were higher. When considering instantaneous short circuit in GMAW-P, it occurs in two forms: Peak instantaneous short circuit (PIS) and Base instantaneous short circuit (BIS). Both of these, PIS and BIS occur during peak and base time of a pulse cycle and are shown in Figure 4 on a voltage waveform.

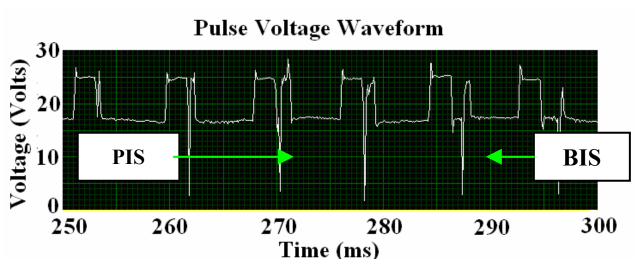


Fig. 4. Voltage waveform of instantaneous short circuit condition in GMAW-P

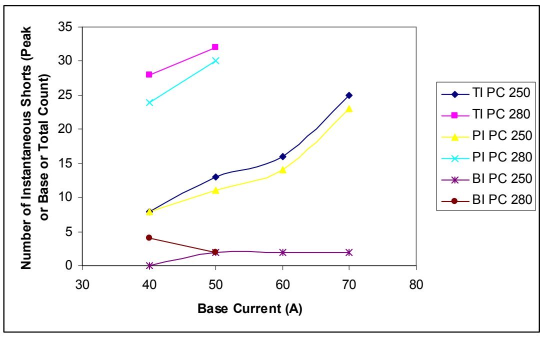
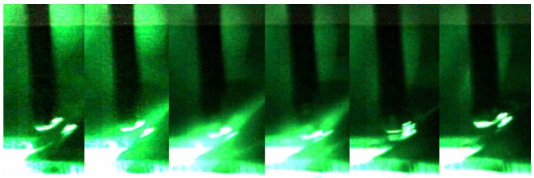


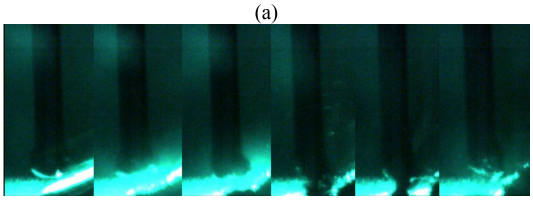
Fig. 5. Different Types of Instantaneous Shorts (Total, Peak and Base) at Peak Time 2 ms and Base time 17 ms with Increasing Base Current and Peak Current *(* TI – Total Number of Instantaneous Short Circuit, and PC – Peak Current)*

Most of the instantaneous short circuits occurring in GMAW-P occur only in the forms of PIS as depicted in Figure 5 in which PIS curve is very close to total number of instantaneous short circuit curve. PIS were generally observed to be more when peak and base current were higher (Figure 5). Figures 6 (a) and (b) shows images of the experimental runs under different base current conditions.

The reason for the increase in PIS with increasing base current can be attributed to three reasons: (i) Increased wire melting rate because of higher average current, (ii) reduced arc length which can be confirmed from Fig. 6 (a) and (b), and (iii) the droplet formed at the end of the electrode does not have sufficient energy to detach itself as surface tension is the predominant force during base time preventing transfer.



(a)



(b)

Fig. 6. Experimental run showing PIS occurring at peak current 250 A, peak time 2 ms and base time 17 ms at base current of (a) 40 A, and (b) 60 A

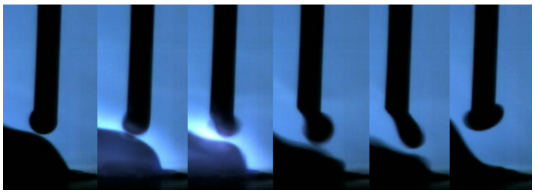


Fig. 7. Experimental run showing PIS occurring at peak current 280 A, peak time 2 ms, base current 40 A and base time 17 ms

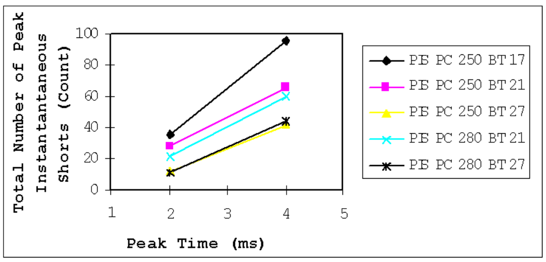
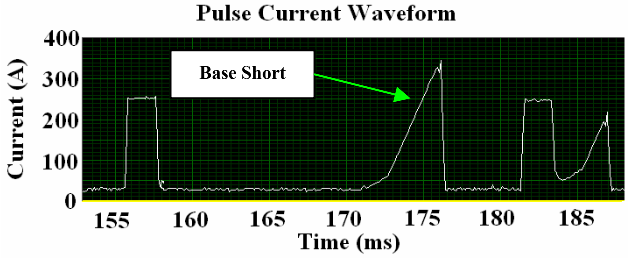
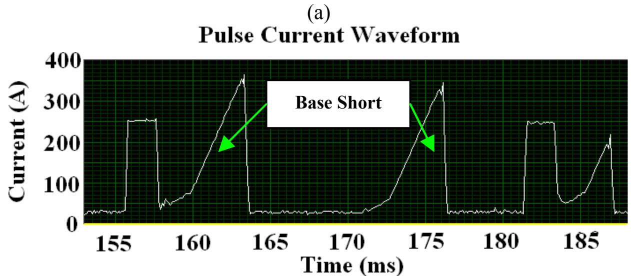


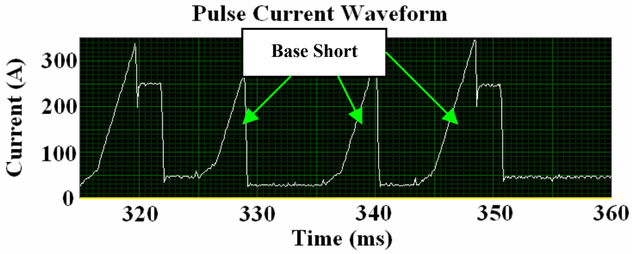
Fig. 8. Peak Instantaneous Shorts at peak current 250 A and base current 40 A with increasing peak and base time



(a)



(b)



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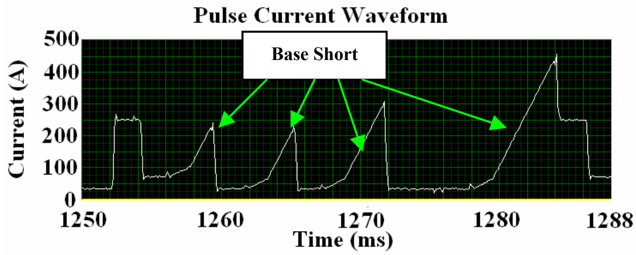
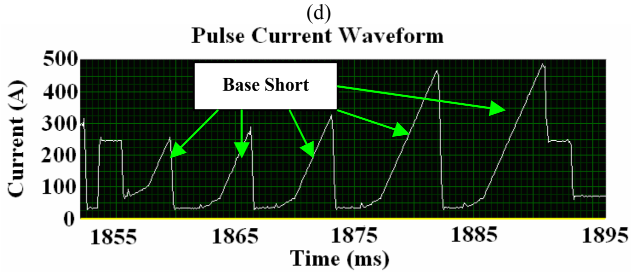


(d)



(e)

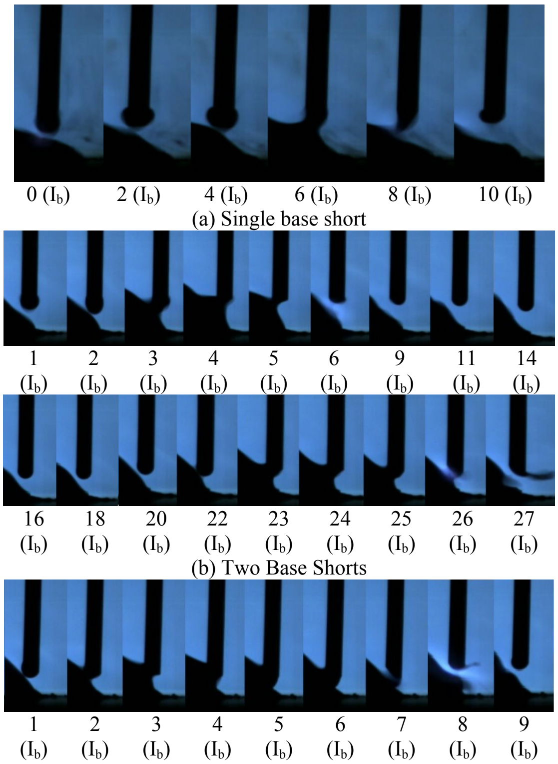
Fig. 9. Various forms of base shorts are shown on current waveform when short circuit occurs during base time (a) Single base short, and Multiple base shorts - (b) Two base shorts, (c) Three base shorts, (d) Four base shorts, and (e) Five base shorts

Figures 6 (a) and 7 shows images of the experimental run at higher peak current. Increased PIS are observed at higher peak current because of elongation of the pendant drop at the end of the electrode which comes in contact with the weld pool momentarily before recoiling back to spherical shape. PIS was generally observed to decrease with longer peak time. However, PIS was observed to be more when peak time was longer and base time was longer (Figure 8).

Base Shorts

In base shorts, the electrode touches the weld pool for a period (> 1 ms in this case) of time during the base time of pulse and actual metal transfer takes place. When considering base short circuit in GMAW-P, it occurs in two forms depending upon the number of times short phenomenon occur during the base time: Single base short, and Multiple base shorts (Two, Three, Four or Five base short circuits). All of these forms of base short circuits can be detected on current waveform as shown in Figure 9.

Base shorts are generally observed to be more when base time is longer and base current is smaller (Figure 11 (a)). Figure 10 shows images of different forms of base shorts observed in the experimental runs. Figure 10 (a) shows images of single base short occurring in frame 4 with background time of 11 ms. However, when background time is raised to 27 ms, keeping all other pulsing parameters constant, multiple base shorts occurring during base conditions have been shown in Figures 10 (b)-(e). In Figure 10 (b), short occur only twice in frame 3 and 13 with background of 27 ms. Single and two base shorts are most frequent form of base shorts. Two base shorts are occasionally observed at lower base times. Multiple base shorts in the form three, four and five base short can be seen in Figure 10 (c), (d) and (e) respectively under same conditions with 27 ms background time. Figure 11 shows the variation in total number of base shorts and multiple base shorts with different base currents and time.



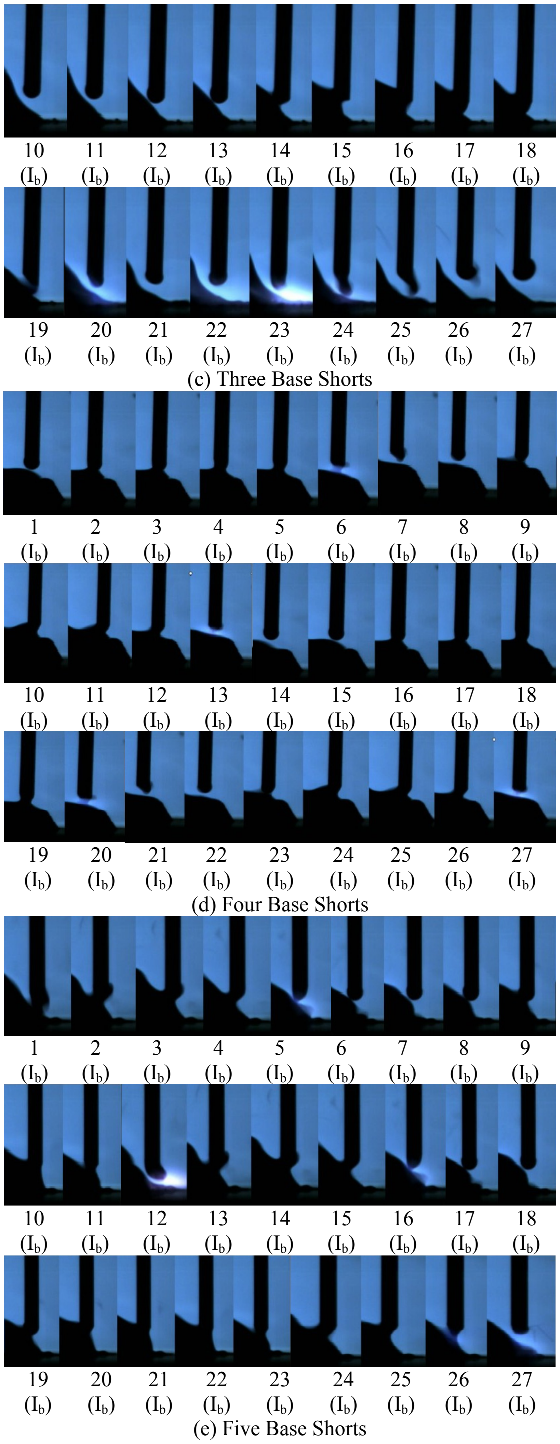


Fig. 10. Experimental run showing different types of base short occurring during base time of the one pulse cycle at peak current 280 A, base current 40 A and peak time 2 ms, in the different forms namely: (a) Single base short with base time of 11 ms, and Multiple base shorts with base time of 27 ms in the form of: (b) Two base shorts, (c) Three base shorts, (d) Four base shorts, and (e) Five base shorts

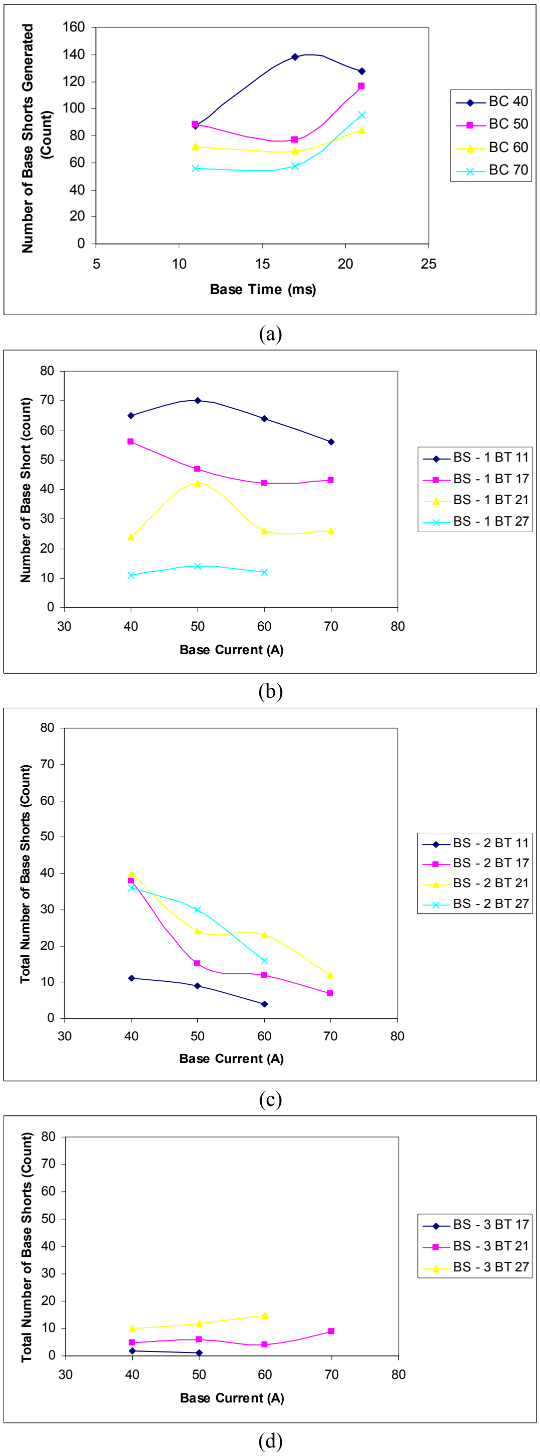


Figure 11. Variation with increasing base current and base time (at peak current 250 A and peak time 2 ms) of (a) Total number of base shorts, (b) Single base short, and Multiple base shorts - (c) Two base short, and (d) Three base shorts *(* BC – Base Current, BT – Base Time, BS - 1 – Single Base Short,BS-2 – Two Base Shorts, and BS-3 – Three Base Shorts)*

Base shorts are found to decrease with increasing base current. The possible reason for this is similar behaviour pattern of both single and multiple base shorts of being more dominant at lower base currents (Fig. 11). The reason for the reduction of base shorts with increasing base current can be attributed to two reasons: (i) Increased wire melting rate at higher base current because of higher average current, and (ii) the droplet detaches more in the form of droplets rather than short which can be confirmed by the time between starts of successive shorts. It was found to be 16.91 ms and 19.62 ms for lower and higher base current for single base shorts. For multiple base shorts average time between start of successive shorts was found to be 10.3 ms and 10.9 ms for lower and higher base current. Longer times between the successive shorts are the indication of lower number of shorts observed at higher base current. Even though there was reduction in arc length observed at higher base current which may suggest increase in base shorts. But because most of the drops gained sufficient energy to detach themselves as a result there was a drop in base shorts observed.

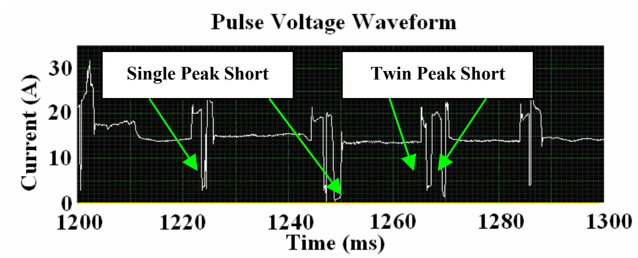


Fig. 12. Various forms of peak short circuit shown on current waveform when short occur during peak time of pulse (a) Single peak short, and multiple peak shorts - (b) Twin peak shorts

Base shorts are found to increase with increasing base time. The possible reason for this is difference in behaviour pattern of single and multiple base shorts which are single base shorts are found to be more dominant at lower values of base time whereas multiple base shorts are found to be more dominant at higher values of base time (Figure 11 b-d). At lower values of base time, melting rate will be higher resulting in longer arc length and hence single base shorts are found to be more dominant. Also peak shorts and instantaneous shorts are more at lower base time as peak conditions will be more dominating which will result in elongation of the molten drop at the end of the electrode. At higher values of base time, melting during base time will be very low resulting in shorter arc length and hence multiple base shorts will be more dominant. Also peak shorts and instantaneous shorts are less at higher base time as most of the metal transfer from the electrode will be transferred in the form of multiple base shorts.

Peak Shorts

In peak shorts, the electrode touches the weld pool for a period (> 1 ms in this case) of time during the peak time of pulse and metal transfer takes place. When considering peak short circuit in GMAW-P, it occurs in two forms depending upon the number of times short phenomenon occur during the peak time: Single, and Multiple peak shorts (Twin peak short circuits). All of these peak short circuits can be detected on voltage waveform as shown in Figure 12.

Peak shorts were generally observed to be more prevalent at lower peak current, lower base time and higher base current. Figures 14 and 15 shows images of different forms of peak shorts observed in the experimental run. Figure 10 shows images of single peak short occurring in frame 3 with peak time of 2 ms. In Figure 15, Multiple peak short in the form of twin peak short with short occurring only twice in frame 6 and 8 with peak time of 4 ms was observed. Single peak short was the most frequent form of peak short found in experimental runs. Twin peak short was occasionally observed at higher peak times and base time.

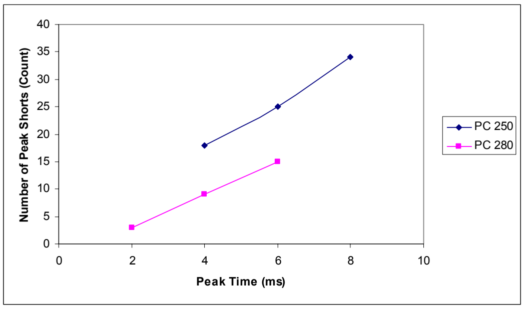


Fig. 13. Variation of total number of peak shorts with increasing peak current and peak time (at base current 40 A and base time 27 ms) *(* PC – Peak Current)*

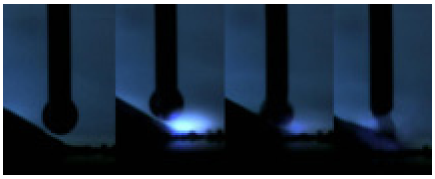


Fig. 14. Experimental run showing single peak short occurring during base time of the one pulse cycle at peak current 280 A, base current 60 A, peak time 2 ms, and base time 27 ms

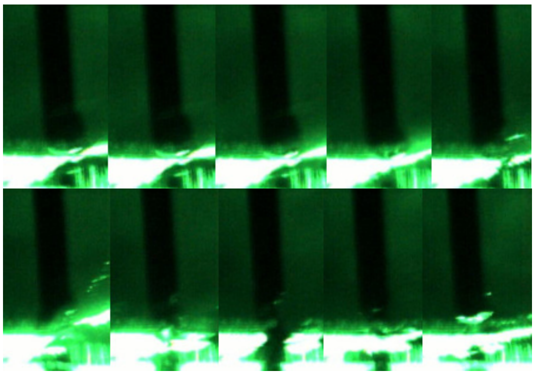


Fig. 11. Experimental run showing Multiple peak shorts (Twin peak short) occurring during peak time of the one pulse cycle at peak current 250 A, base current 40 A, peak time 4 ms, and base time 17ms

Peak shorts were found to decrease with increasing peak current (Figure 13). At higher peak current, possible reason for the decrease in peak shorts can be attributed to two reasons: (i) Increased wire melting rate as peak condition are more dominate, and (ii) of the pendant drop at the end of the electrode which comes in contact with the weld pool momentarily before recoiling back to spherical shape. Peak shorts were generally observed to decrease with longer peak time. However, Peak Shorts were observed to be more when peak time was longer and base time was longer (Figure 13).

Fig. 16. Butting of electrode into workpiece at very low arc lengths which occurred at peak current 280 A, base current 40 A, peak time 2 ms, and base time 27ms

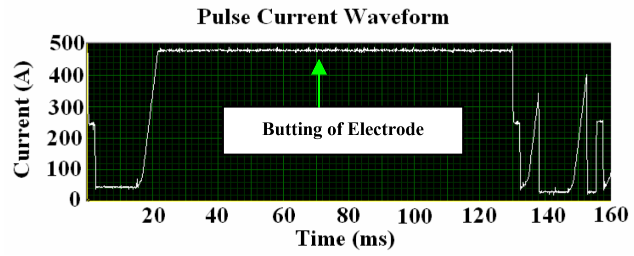


Fig. 17. Butting of electrode into workpiece as seen on current waveform

Butting of Electrode into Work piece

In butting of electrode into workpiece, wire melting rate of the wire is very low as a result arc length becomes very small, electrode touches the workpiece and get struck in to it as shown in Figure 12 for a very long time. Butting of electrode in to workpiece can be detected on current waveform as shown in Figure 17.

Generally butting of the electrode in to workpiece occurred at lower peak time and higher base time as melting rate of the electrode is very low under these conditions.

5. Conclusions

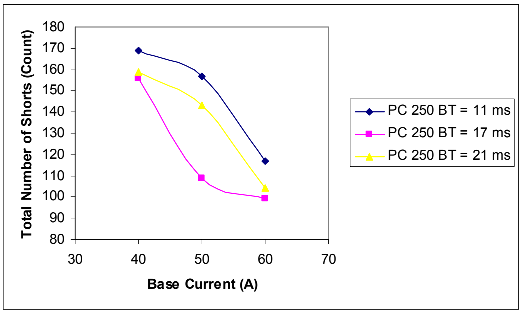
The results show that by varying the pulse parameters, behaviour of short circuit in GMAW-P is changed. The pulse parameters can be adjusted to avoid occurrence of short circuit in GMAW-P.

For a stable GMAW-P, arc length must be maintained constant. However at short circuit electrode makes contact with the workpiece indicating that arc length is not constant. As arc length is very short during short circuit, poor selection of pulse parameters in GMAW-P resulting in only wire melting rather than droplet detachment can in turn result in more number of short circuits in GMAW-P system. Wire melting in GMAW-P is dependent upon peak and background conditions of the pulse.

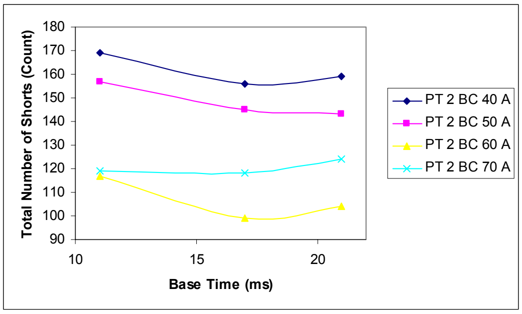
At higher values of peak conditions, which mean higher peak current and peak time, wire melting was found in the form of detachment of pendant droplet at the end of the electrode overcoming the surface tension force. Hence, with increasing peak current and peak time number of shorts was found to be less.

Thus dominant peak conditions are a good choice to avoid short circuit in GMAW-P.

At higher values of base currents, number of shorts were found to decrease (see Figure 18 (a)) because of increased melting of wire due to high average current and most of the pendent drop formed at the end of the electrode gained enough energy to overcome surface tension force and detach. Thus increasing base current is a good choice to avoid short circuit in GMAW-P.



(a)



(b)

Figure 18. Variation of total number of shorts with increasing (a) base current, and (b) base time (at peak current 250 A and peak time 2 ms) *(* PC – Peak Current, PT – Peak Time, BC – Base Current, and BT – Base Time)*

There was no change observed in the number of base shorts with increasing base time (see Figure 18(b)) as at lower base time peak and instantaneous shorts were more dominant and at higher base time multiple base shorts were more dominant. This may suggest that base time doesn't have much influence but infact, with higher value of base time butting of electrode into the workpiece was observed, which is undesirable. Hence lower base time is a good choice to avoid short circuit in GMAW-P.

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