Evaluation of Arc Welding Process using Digital Storage Oscilloscope and High Speed Camera

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ABSTRACT

Digital Storage Oscilloscope (DSO) and a high speed camera with laser light illumination are used to monitor manual metal arc (MMA) welding process. Welding was carried out using different type of welding power sources and electrodes. Dynamic variation in current and voltage was recorded using a DSO with very high sampling of four Giga samples/s. Arc welding process was imaged using high speed camera simultaneously. Data obtained from DSO were subjected to time domain and statistical analysis. Probability density distribution (PDD) analysis of the voltage and current signals were carried out.

The results showed that a proper filtering should be applied for the raw data collected using DSO to generate useful information. It was possible to correlate various physical processes that occur during welding with corresponding variations in voltage and current. High speed images from the camera enabled to view the physical processes that occur during arc welding and hence helped to obtain this one to one correlation. Statistical analysis showed that PDD generated from the acquired data is unique to a welding power source or a consumable or a welder. Hence PDDs can be used to evaluate performance of power sources or consumables. Accordingly, separate PDDs for a inverter and a generator power source were produced. By combining both imaging and DSO signals it was also possible to show different modes of metal transfer in arc welding process. Thus the feasibility of monitoring arc welding process using DSO and high speed camera has been demonstrated successfully.

Keywords: Metal transfer; arc welding; high speed imaging; statistical analysis; welding signal analysis.

1.0 INTRODUCTION

Manual Metal Arc (MMA) welding is one of the popular welding processes due to versatility in process, simplicity in operation and relatively low maintenance cost. This process is extensively used in construction and fabrication of structural materials in nuclear industry. Welding is a stochastic process due to random behavior of various metal transfer modes like short-circuit, globular, spray projected and explosive transfer occurs during welding process. In this study, MMA welding process is evaluated and analyzed using DSO signal and high speed camera video frames for comparison of performance of power sources and quality of electrodes. To evaluate the process, welding current, voltage and corresponding high speed video frames were recorded. Similar studies have been reported in literature. Jullien Chapuls et al. [1] synchronized current and arc voltages process data with high speed camera video frames for analysis of droplet-gas interaction during GMAW process. The detailed metal transfer is investigated by droplet size, shape and speed of droplet into plasma and obtained weld parameter result is correlated with physical parameters.

During welding, many problems are encountered to record the welding signals because of high level of background noises, electrostatic and electro-magnetic noises generated during arc ignition and arc extinction. These noises affect the true information of welding signal by creating a impulse response in original welding signal. In order to extract the true information from welding signal a high pass filter is applied. Special care is also taken to measure the welding current through Hall Effect sensor probe and voltage is measured with differential probe and is connected through twisted shielded pair cable. Andrej Lebar et al. [2] developed a new concept for monitoring and analyses of welding parameters by microcontroller and used Hall Effect sensor for measuring welding current. Adolfsson et al. [3] enhanced the welding signal using high pass filter with elliptic discrete time filter. Time domain analysis were carried out to investigate arc time, short-circuit time, peak current, voltage during arc time and voltage during short-circuit time.

Metal transfer modes are important to understand the arc behavior during MMA welding. Molten metal droplet is formed initially at the tip of the electrode and grows gradually. The metal transfer can occur either due to short-circuiting between molten metal and the base metal or by an mild explosion drop at the tip of the electrode. Each short-circuit is accompanied by significant drop in voltage with corresponding increase in current value. From the recorded data, variations of welding current and voltage can be analyzed by statistical methods. Praveen et al. [4] carried out statistical method of multiple linear regressions for estimating the droplet transfer mode in the form of number of drops per pulse and developed model is proposed for online monitoring of automatic welding process. Adam et al. [5] evaluated the metal transfer modes by Fourier transform and frequency of histogram method. The detailed study was carried for current and voltage signal for automated welding system using microcomputer. Electrode evaluation is very important for industry to increase the productivity, optimize the power consumption, improve the quality and ensure defect free welding. Liu et al. [6] carried out measurement of arc current and voltage during short-circuiting of metal transfer for quantitative measurement of transfer of stability for optimizing weld parameters by characterizing droplet rates for various transfer modes.

In the present study, MMA welding process is monitored using a digital storage oscilloscope (DSO) and high speed camera, and variation in the performance of different types of welding power sources and consumables are studied.

2.0 EXPERIMENTAL SETUP

The experiments were carried out on 12mm thick plates of dimension 300mm long and 300mm width on carbon steel with E7108 electrode dia of 3.05 mm by arc welding. The Agilent make Infivision 7054B, 500 MHz band width with maximum 4 Giga samples per second digital storage oscilloscope is used to monitor the magnitude, phase and shape of the welding current and voltage during arc welding process. A Fastcam high speed frame rate digital camera with adjustable frame rate of 4000 frames per second and shutter speed of 1/80000 s is used for monitoring the physical behavior of welding process. A class 4 Short pulsed laser source is used to suppress the bright arc illumination and to clear visible of molten pool and metal transfer during the welding. The high speed camera is connected to industrial computer via frame grabber and laser light source is generated and controlled through laser controller. The DSO is connected to computer to acquire real time signals during welding process. The camera is positioned behind the welding torch and laser head is projected on electrode tip area for optimum illumination to the weld pool. The high speed camera is recorded 16,394 frames for 4.094 second duration of welding process with the frame rate of 4000. The high speed camera shutter speed is synchronized by trigger pulse generated by laser controller to stabilize the motion during each frame capture for precise dynamic process of welding. The Infivision software is facilitating to monitor, record real time video and post analysis with variable frame rates. The schematic diagram of experimental setup is shown in **Fig. 1**.

3.0 WELDING SIGNAL ACQUISITION AND CONDITIONING

The real time welding current is acquired by high sensitive 1mA/A Hall Effect sensor clamp type transducer connected through specialized shielded twisted pair cable. The hall probe is protected from sudden high currents and voltage spikes during switching of high frequency startup in power source. It provides good electrical, physical isolation and provides good dynamic response characteristic in high currents. A high voltage active differential probe is connected across the output of power source to measure the accurate voltage during real-time welding process. It contains signal conditioning pre-amplifiers for sensitive signal measurement of oscilloscope signals and provides high bandwidth, low loading effect and high common mode rejection on measuring probe. Generally the welding signals always consist of electromagnetic radio frequency, electrostatic and magnetic coupling noises due to switching of high frequency power startup and continuous variable current pulsating in the power source. In order to extract the true information from the noisy welding signal a high pass filter was applied to the welding signal after acquiring. **Fig. 2** shows the oscillograms of voltage and current. The top portion shows unfiltered raw data of welding signal and bottom filtered signal.

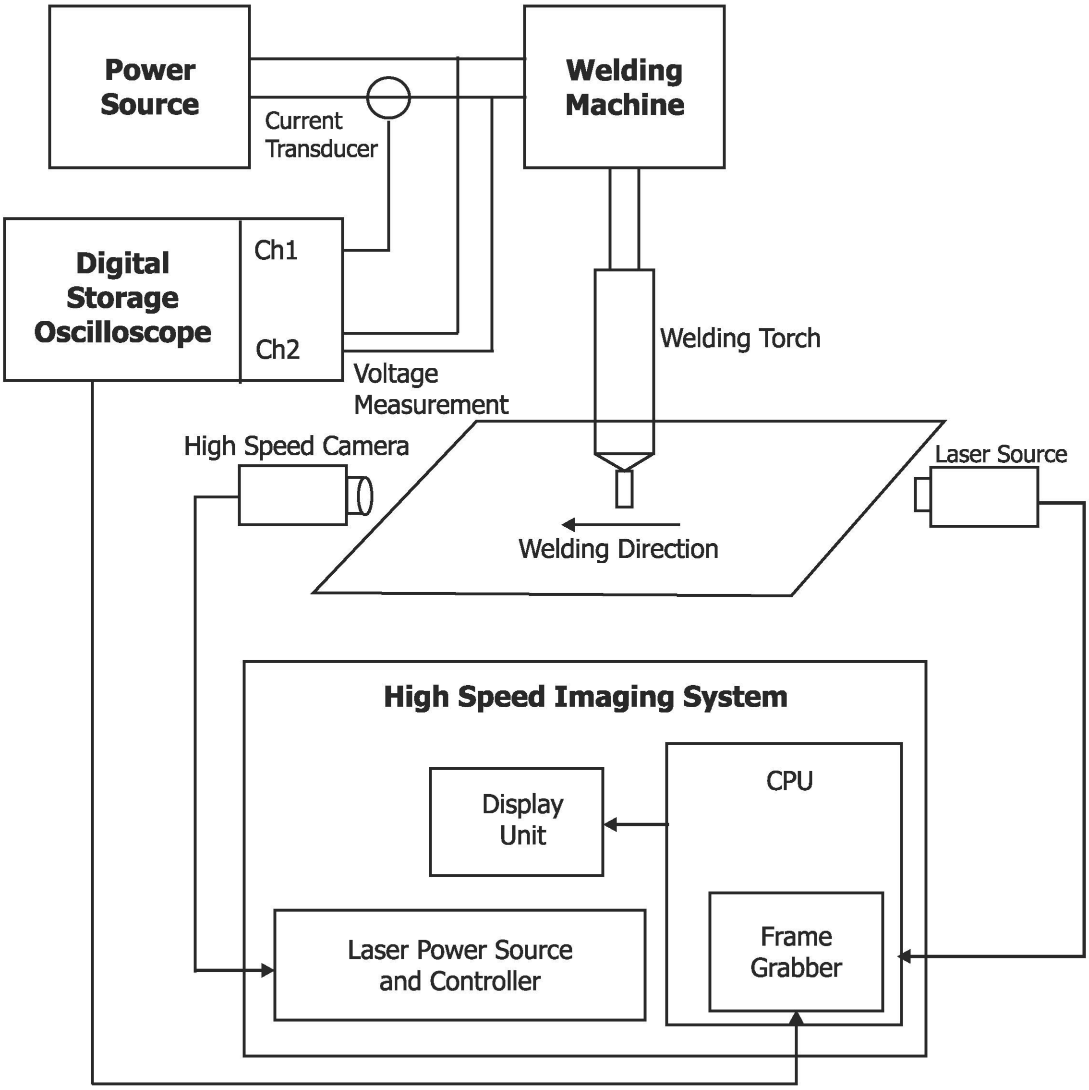

Fig.1 : Schematic diagram of experimental setup with integrated high speed imaging system

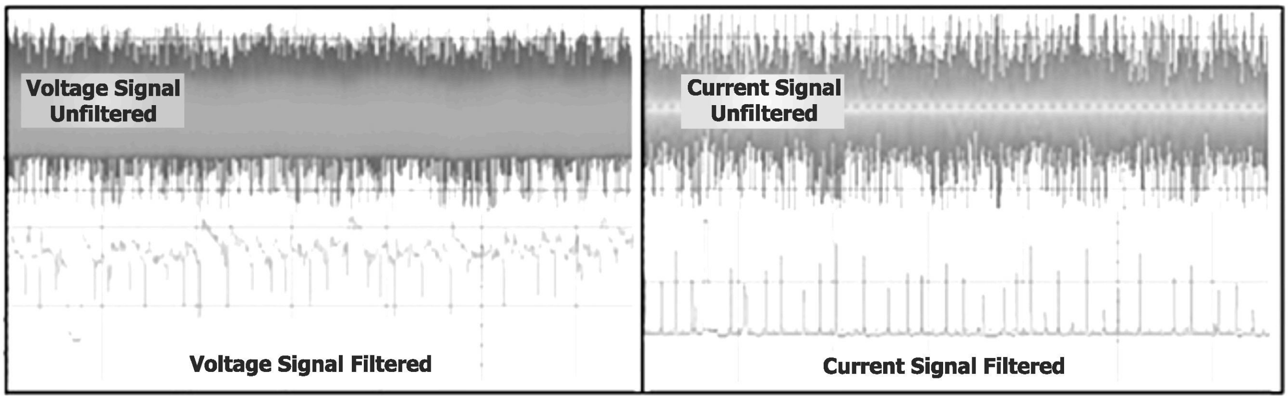

Fig. 2 : Unfiltered and filtered welding signals using high pass filter

4.0 RESULTS AND DISCUSSION

Comparison of power source performance

Fig. 3 shows oscillograms obtained while depositing E7018 electrodes on carbon steel plate using three different welding power sources; one inverter and two generators (Triodyn-K320 and Supergen-320). The deposition was carried with current of 100A. Oscillograms shown here is 1/40th segment of the data collected over a period of five seconds during welding, i.e., for duration of 125 ms. This is generated from one Lakh data points acquired during this period. Sudden drop in voltage observed in the oscillogram corresponds to short-circuit transfer of the molten electrode into the weld pool. Voltage drop is accompanied with corresponding increase in current signal. The duration of variation in the current is very short in the case of inverter power source in **Fig. 3(a)**. this is expected because the inverter power source is provided with a powerful control circuitry which suppresses the increase in current. It may also be noted that at the end of short-circuit there is a dip in current which shows the typical characteristic of the welding power source. In the case of Triodyn-K320 the increases in current during short-circuit is much more than what is observed in the case of inverter. Further the time taken for the current to return to set value (100A) is also long. In contrast to this in the case of Supergen-K320 generator spike in current is not significant; but the set value of current shows wide variation compared to that observed for other two power sources. As expected the response to change in voltage is quick in inverter compared to generators.

From **Fig. 3** it is clear that an oscillogram of welding power sources generated using DSO can clearly bring out differences in the performances of different welding power sources. Similarly one can also compare the performances of different welding consumables or welder using DSO. On-line data acquisition system may also be helpful in detecting defect formation during welding.

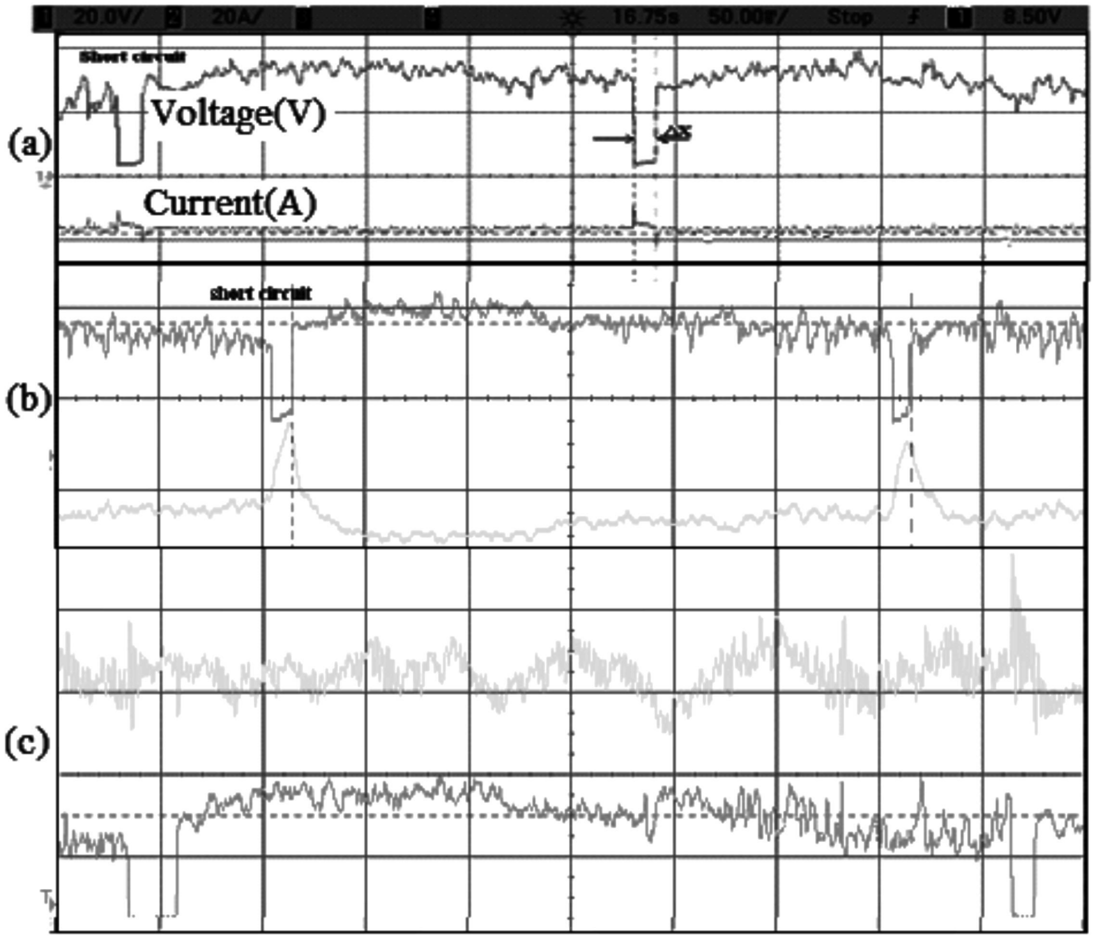

Fig. 3 : Performance comparison of power sources for a) Inverter b) Generator (Triodyn- K320) and c) Generator (Supergen-320) during short-circuit of metal transfer

5.0 STATISTICAL ANALYSIS OF THE DSO SIGNALS.

The results shown in **Fig. 3** are time domain analysis of the voltage and current signals acquired during welding. This signal can be statistically processed to generate probability density distribution (PDD) function, which could be characteristics of a particular type of power source. However, for this data should be acquired with very high sampling rate. **Fig. 4** shows the PDD function generated for inverter using 1000, 10000, 40000 and 100000 sampling data acquired for the same period (125 ms). PDD for the voltage shows broad variation in voltage; when PDD is generated using less sampling rate. However a clear pattern which reveals short-circuiting and steady sate conditions emerges with increasing sampling rate. The percentage fraction at low voltage of the PDD corresponds to short-circuit that occurs during welding and percentage fraction around 20 volts corresponds to the steady state. Similarly in the case of PDD for current with low sampling rate the current variation that occur during short-circuit is not evident. However, at high sampling rate the PDD reveals increase in current that occur at the beginning of short-circuit and decrease that occur at the end of short-circuit.

Fig. 5 shows two separate PDDs of current and voltage obtained for two different weld trials made at identical conditions using Supergen-320 generator using one Lakh data points acquired in 125 ms. Comparison of **Fig. 4** and **Fig. 5** shows the PDD for current of inverter and generator is significantly different. PDD for generator reflects wide variation in current observed in the time domain analysis of oscillograms. The almost identical PDDs obtained for two different welds produced using same machine clearly show that PDDs are characteristic of a power source. Hence PDDs generated for different power sources can be used for comparing the quality of these power sources. Similarly variations in PDD of the same power source over a period of time would be indication of the change in the performance of power source. Further for a given power source difference in PDD for different welding consumables or different welders can be used to evaluate their performance.

6.0 METAL TRANSFER DURING WELDING

Voltage and oscillograms collected during welding process can be complimented by imaging arc welding process using high speed camera with laser illumination. **Fig. 6 (a-d)** show video frames of short-circuit transfer during welding using E6010 electrode and an inverter power source at 100A. The corresponding oscillogram for current and voltage are shown in **Fig. 6e**. the video frames are for the part of the oscillograms that indicates short-circuit transfer. **Fig. 7 (a-d)** are the video frames obtained while depositing E6013 electrode using same power source and at same current. Corresponding

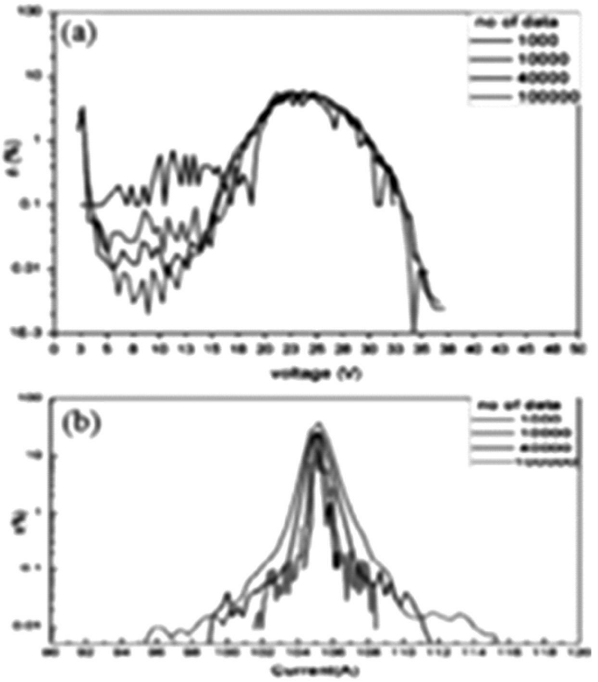

Fig.4 : (a) voltage and (b) current PDDs of inverter power source

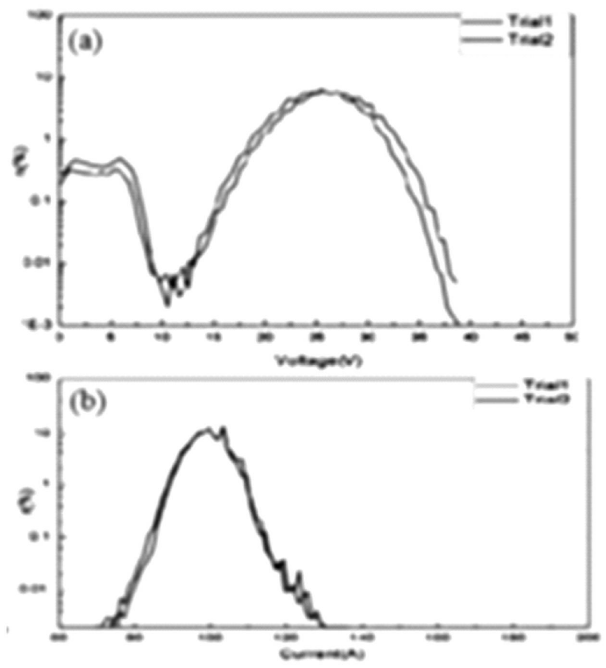

Fig.5 : (a) voltage and (b) current PDDs of Generator power source (Supergen 320)

oscillograms are shown in Fig. 6e. It may be noted there is no sudden drop in voltage in the oscillograms corresponding to metal transfer shown in the video frames. Instead there is a gradual reduction in the voltage, a steady state and then sudden increase, indicating arc gap is decreasing just before the metal transfer and increasing suddenly at the end of transfer. A close look at the video frames can reveal this change in arc gap. Hence, in this case metal transfer is not through short-circuit. Molten metal drops from the electrode tip into the weld pool. It appears from the video frames that molten slag covers the molten metal during this transfer.

From the above examples shown it is clear that by combining high speed images of arc and oscillograms acquired during welding, one can get very useful information on physical processes that occur during welding. Once signatures in the oscillograms corresponding to various physical processes during welding are identified by combined use of high speed imaging and DSO, it should be possible to monitor welding process using DSO alone. Such a study will be useful to monitor performance of welding power sources, consumables and welding personnel.

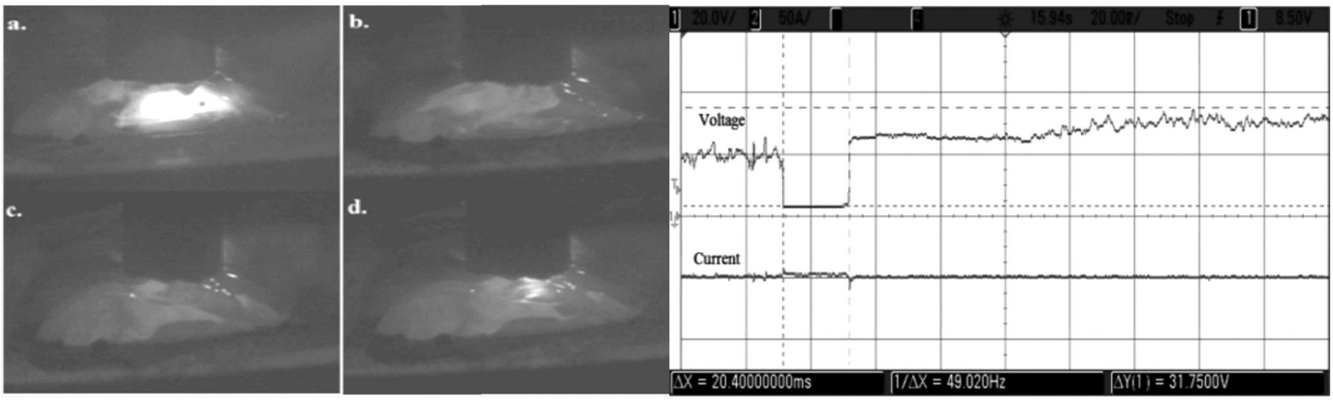

Fig. 6 (a-d) : High speed video frames showing metal transfer during welding using E6010 electrode and e) the corresponding oscillogram.

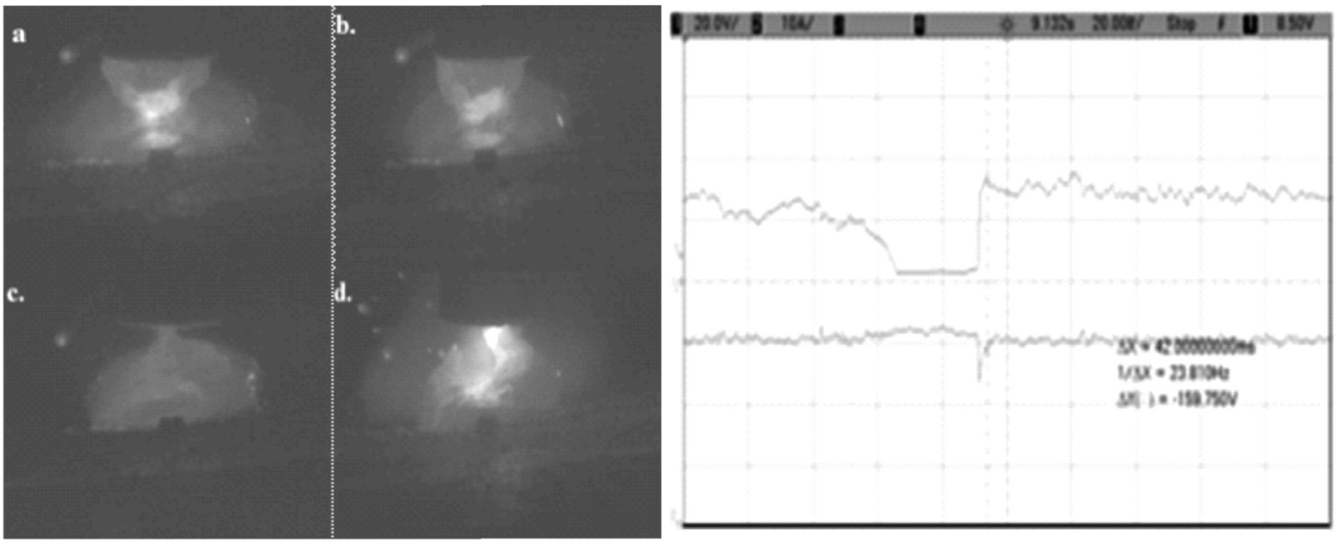

Fig. 7 (a-d) : High speed video frames showing metal transfer during welding using E6013 electrode and e) the corresponding oscillogram.

CONCLUSIONS

The major conclusions present study is the following:

1. It is demonstrated that by synchronizing data acquisition using DSO and high speed imaging it is possible to study various physical process that occur in a welding arc.
2. Filtering of noise using appropriate filters is necessary for extract useful information the oscillogram.
3. PDD generated from the oscillograms acquired at a very high sampling rate can provide reliable information on the dynamic variation voltage and current that occurs during welding. Hence PDDs can be used as a characteristic of the welding power source consumables or welder.
4. By combining high speed images and oscillograms one can find out different modes of metal transfer that take place during welding.
5. It should be possible to develop a correlation between physical process that occur during welding that corresponding variation voltage and current, so that DSO alone can be used to understand the arc welding phenomena.

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