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METAL TRANSFER BEHAVIOR OF PLASMA ENHANCED SHIELDED METAL ARC WELDING (PESMAW)

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ABSTRACT : *The mode of metal transfer during Plasma Enhanced shielded metal arc welding (PESMAW), a modified version of the conventional manual metal arc welding (SMAW) was studied. PESMAW is a recently developed concept that uses tubular coated consumable electrodes, aims to make the SMAW towards more environmentally friendly by eliminating organic cellulose in the flux coating. The transfer behavior was characterized on non-cellulosic, rutile coated electrodes (EXX13) by recording the arc signals in real time using a high-speed data acquisition system. The analysis was done by plotting the welding voltage and current histogram to estimate the arc voltage and current fluctuations. The results showed that the pattern recognition of several kinds of metal transfer modes for the PESMAW can be ascertained along with accurate measurement of relative important process parameters. The metal transfer behavior was found to be generally under mixed mode, predominantly globular and occasional spray at higher current levels while at lower current levels mostly globular and occasional short circuiting transfer were found.*

KEYWORDS: Metal Transfer; PESMAW; VI Transients

1.0 INTRODUCTION

The Plasma enhanced shielded metal arc welding (PESMAW), a modified version of conventional manual metal arc welding (MMA) process, was primarily developed to eliminate the usage of organic cellulose from the flux composition of the consumable electrodes (EXX10) in order to save the environment and to improve metallurgical performance of weldments [1]. The environmental concerns of using cellulose is well known, since the diffused hydrogen from cellulose decomposition during welding has been proven to be the root cause for the infamous hydrogen induced cold cracking (HICC) which demands huge inspection costs and sporadic fatal failures. PESMAW uses gas fed tubular coated welding electrode, coated with either rutile (EXX13) or low hydrogen (EXX18) to counter balance the effects attributable to the cellulose. According to Pandey et al. [2], the supply of auxiliary gas at a controlled volume flow rate to generate laminar flow through the tubular electrode (Figure 1) into the induced electric arc during welding will induce an auxiliary plasma - the compensating equivalent to the well known effects attributable to the organic cellulose for high penetration and weld performance. The presence of controlled gas supply through the orifice of tubular electrode into the high temperature electric arc generally affects the metal transfer behavior of the welding process. The metal transfer in arc welding, which refers the molten metal that is transferred from the electrode tip to the weld pool, affects spatter, fume level, positional capabilities, arc stability and overall weld performance [3, 4]. The study of the mode of metal transfer in arc welding is difficult, as it not only involves a number of factors but also is dynamic in nature. The size of the droplet and the rate of droplet transfer affect the weld bead geometry, weld metal microstructure and the overall strength of the welded joint. The control of metal transfer through different factors can therefore improve the properties of the weldment considerably. There have been several attempts to classify, on a phenomenological basis, the numerous transfer modes observed in welding [5, 6]. The International Institute of Welding (IIW) classification of metal transfer [7] has referred to about 12 different modes of metal transfer, but three types, namely, short circuit, globular and spray mode of metal transfer are most commonly recognized in practice. Most of the published work on behavior of metal transfer during arc welding involves gas metal arc welding or flux cored arc welding. In spite of the importance of investigating the metal transfer from covered electrodes, there has been little work devoted to the systematic and quantitative analyses of mechanism of metal transfer. This is because of the fact that the mechanism of metal transfer is difficult to establish since the arc is partially obscured by fume and particles of slag. In addition, in many cases, a deep cavity formed by the covering hides the tip of the electrode from view. Furthermore, the PESMAW differs from both gas metal arc welding and flux cored arc welding in that it is an inherently transient process.

In general, the molten metal during transfer consists of globules [8] that short circuit the arc at one extreme, or a fine, showery spray of metal and slag particles that, because of their small size are unable to create a short circuit. The showery spray transfer is desirable [9]. For SMAW, three metal transfer modes are generally active [10]. These modes are fine droplet transfer (Figure 2(a)), explosive transfer and short circuit transfer (Figure 2(b)). Short circuit transfer generally occurs with basic (lime) coated low hydrogen electrodes and for all other coated electrodes (rutile, cellulosic etc.,) it occurs only at low current levels. Explosive transfer, characterized by the

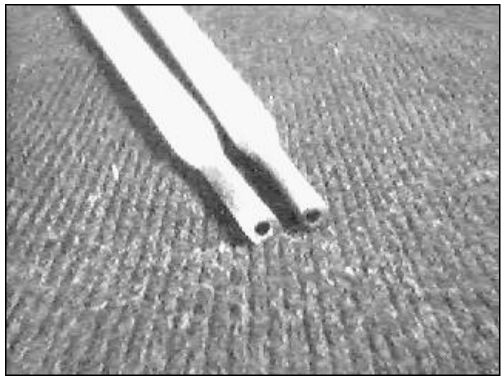

Figure 1: Tubular covered electrodes used in PESMAW process

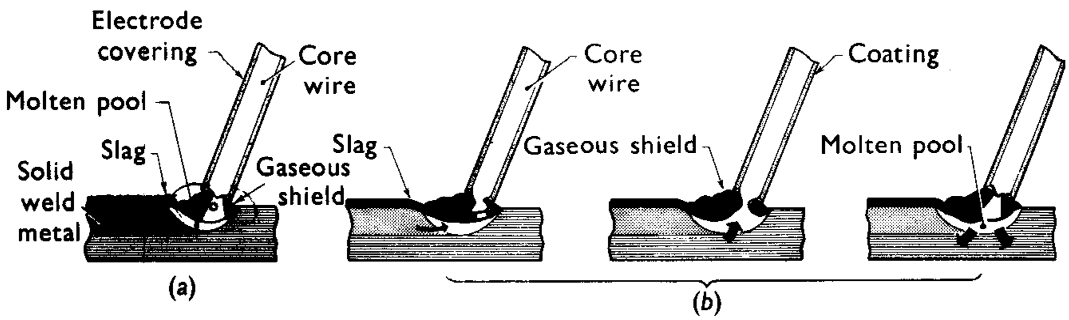

Figure 2: Modes of metal transfer in MMA. (a) Spray (b) Stages in transfer by bridging [13]

random separation of droplets from the liquid metal at the tip of the electrode, occurs with cellulosic electrodes. Rutile coated electrodes, exhibits fine droplet transfer at similar current levels. Brandi et al.,[11], identified slag guided transfer as one of the primary transfer modes along with the conventional explosive and short circuit modes during their study on SMAW process for E6011 (cellulosic, E6013 (rutile) and E7018 (low hydrogen) electrodes. The transfer mode was characterized by welding on a rotating copper disk, collecting the droplets in water, and screening the droplets.

In the current work, the transfer of droplets was studied for E6013 rutile covered tubular electrode. The technique of studying transfer behavior by the correlation of arc signals and droplet measurements is well established for GMAW and FCAW and for SMAW to a little extent [12].

2.0 EXPERIMENTAL PROCEDURE

The transfer mode and the possible changes in the transfer mode of the molten metal from the electrodes during welding were characterized for four different conditions: The electrodes used were 3.2 mm in diameter and the length was approximately 355 mm. A 6.3-kVA constant current, inverter power supply, switched to the shielded metal arc-welding mode, was used. The inductance setting was constant.

2.1 Acquisition of Arc Signals and Subsequent Processing

Current and voltage sensors are considered to be the most reliable, simple such that the metal transfer modes were identified with several types of pattern-recognition systems synchronized with the sensor signals [13]. For the study and analysis of metal transfer in PESMAW process, the voltage and current transients were filtered and

recorded in real time, using a portable oscilloscope with in-built analog to digital converter. The welding current was measured by using a 'Hall effect' closed loop current sensor with a response time of less than 3 μs. The test circuit was calibrated by using high precision digital multi-meters at different arc current and voltage settings. For the analysis, the data stored in the digital oscilloscope was transferred to a microcomputer by a program. Several instantaneous key characteristic parameters of the signals were processed from the transients and were stored for further analysis. The welding voltage was measured between the work piece and the electrode holder. The arc voltage, the voltage drop along the remaining length of the electrode, and the voltage drop at the contact resistance between the electrode, therefore, contributed to the welding voltage. Table 1 gives the welding conditions used. A photographic image of the experimental set up is given in Figure

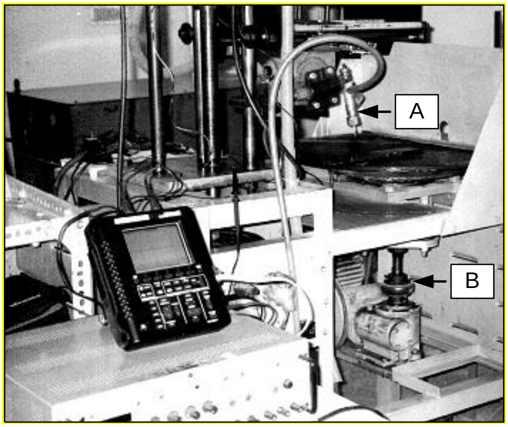

Figure 3: The experimental set up; A-The Universal Electrode Holder (UEH), B-the stepper motor for down feed movement

Table 1: Experimental welding conditions.

Exp No.	Welding Current, A	Open circuit voltage, V	Welding speed, mm/min	Electrode angle, Degree
1.	110	90	240	60
2.	90	90	240	90
3.	110	90	120	90
4.	90	90	120	60

3 .RESULTS AND DISCUSSION

The relationship between the voltage and current, during any welding process depends on the dynamic voltage-current characteristic of the power supply and in general, the welding voltage is a linear function of the current. The characteristic of the power supply, and specifically the straight line with a finite slope, implies that either the voltage or the current could be used to characterize the transfer the transfer behavior. During welding, a heavy current flows. The inductance in the circuit limits the rate of change of welding current and the voltage & current cannot vary independently. Therefore, even small variations in the welding voltage, as measured during welding, were due to transfer events, and not the line frequency. When examining the arc voltage, current-time plots for the tubular rutile covered electrodes, an obvious distinction could be made over the characteristics of metal transfer that the process had gone through. These results clearly demonstrated that the VI transients shown in Figures 4-7 exhibit predominantly "mixed mode" of metal transfer that comprises substantially, globular transfer with considerable presence of spray and occasional short-circuiting. This transfer behavior was found to be consistent at both high and low current levels at constant arc travel rate. At high current and arc travel rate the arc voltage remained mostly less fluctuated to the extremes (Figure 4). Not a single short-circuiting voltage signal was recorded at this range, apart from the two minor spikes below the average arc voltage. Correspondingly there were no instantaneous shot up of current was recorded. The current signals remained not within the short-circuiting range. It can be clearly seen from the VI transients that at higher current and high arc travel rate the PESMAW process constituted mixed mode with higher percentage of globular and occasional spray. The occasional spikes in the voltage could be attributed to the explosions of the molten metal globes which generally known to be existing in conventional SMAW process [7].

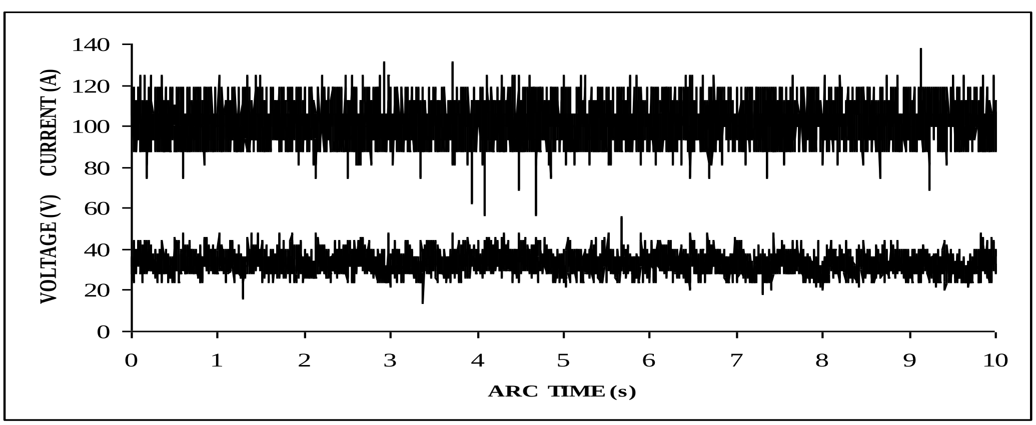

Figure 4: Arc voltage and current signals of PESMAW at welding conditions of 110A, 90V and 240 mm/min travel speed with auxiliary plasma gas supply.

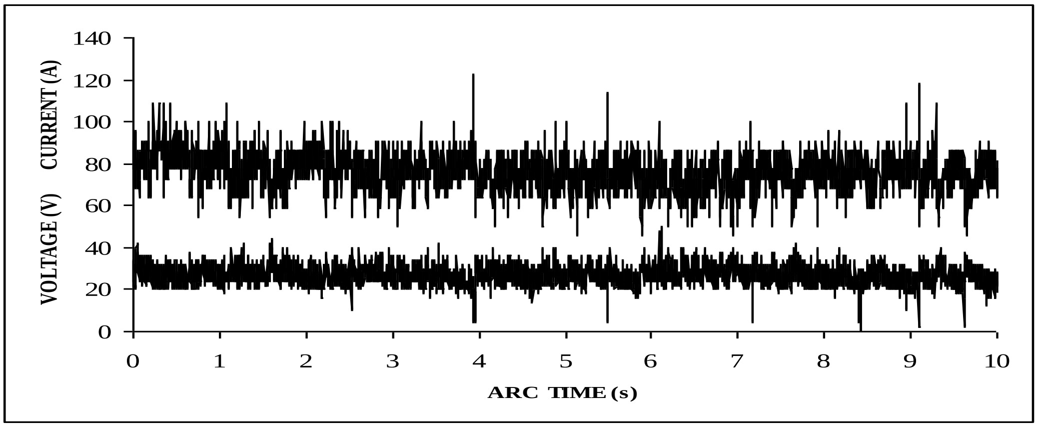

Figure 5: Arc voltage and current signals of PESMAW at welding conditions of 90A, 90V and 240 mm/min travel speed with auxiliary plasma gas supply.

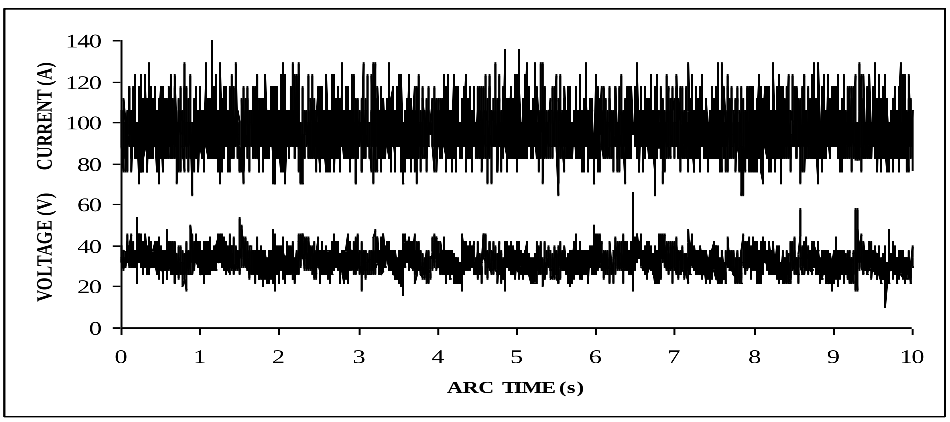

Figure 6: Arc voltage and current signals of PESMAW at welding conditions of 110A, 90Vand 120 mm/min travel speed with auxiliary plasma gas supply.

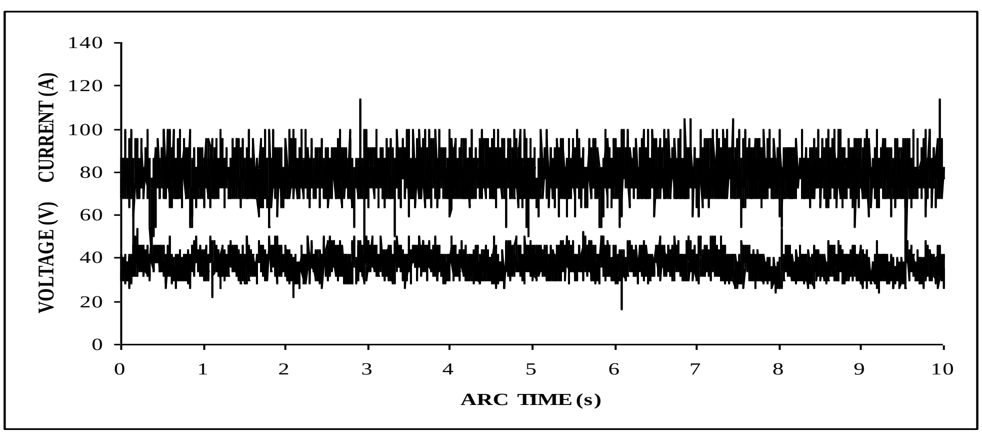

Figure 7: Arc voltage and current signals of PESMAW at welding conditions of 90A, 90V and 120 mm/min travel speed with auxiliary plasma gas supply.

Table 2: Metal transfer modes and relative parameters observed in PESMAW at experimental welding conditions

Exp No.	Mean Arc voltage, V	Mean Arc current, A	Heat Input, kJ/mm	Time Domain	Metal Transfer Mode
1.	34.68	113.25	0.982	Large voltage fluctuations	Mixed mode, predominantly globular and occasional spray, Figure 4
2.	26.80	91.05	0.610	Predominantly Large voltage fluctuations with occasional voltage drops tending to zero	Mixed mode, predominantly globular and occasional short circuiting, Figure 5
3.	34.16	112.45	1.920	Large voltage fluctuations	Mixed mode, predominantly globular and occasional spray, Figure 6
4.	23.97	92.96	1.114	Large voltage fluctuations	Mixed mode, predominantly globular and occasional spray, Figure 7

Figure 5 shows the arc signal histogram recorded at low current, high arc travel rate. The pattern of the arc voltage signals demonstrates that the mode of droplet transfer was generally globular with regular short-circuiting (0 V) seen from the corresponding instantaneous current. Although the short circuiting is attributable to the low current however the high arc travel rate (240 mm/min) causes mainly globular transfer with substantial presence of explosions (refer the corresponding instantaneous current signals).

However, the low arc travel rate does not seem to be changing the transfer mode at higher current levels as can be seen from Figure 6. The arc signals remained predominantly globular with spray. No short-circuiting signals are found in the histogram. This result demonstrates that the arc current is the major contributor to the metal transfer in arc welding. The arc current remained un affected with minor noises recorded. It is well known that the character of metal transfer and size of the metal droplets leaving the electrode in arc welding depend on the heat input which is directly proportional to the arc current. The size of the droplets decreases when the arc current increases. This change proceeds rather gradually at lower currents, but more and more rapidly, as current rises.

Figure 7 shows that at low current and low travel speeds the mixed mode prevailed with prominent globular and regular short-circuiting. There are several low current signals recorded in the histogram, which were attributable to the low arc travel rate.

The decrease of the droplet size leads to a sharp rise of the droplet rate (the frequency of the droplet detachment). This is accompanied by a change of the metal transfer mode from globular at low currents to spray mode at higher currents. The higher presence of globular mode is attributed to the higher current density due to reduced current conduction area even at comparatively lower current range used in the present investigation (90A-110A). Moreover, the presence of controlled orifice gas flow is attributable to the development of globules at the electrode tip during the formation at low currents. Unlike the globular transfer, the short circuiting transfer mode has periodic characteristics of arc and short circuit between the welding wire and the weld pool. The metal droplet grows at the electrode tip when the arc is maintained, and it is transferred to the weld pool while in contact with the tip. Irregular waveforms of the welding current and arc voltage indicate variations in the metal droplet size and imbalance between several forces on the droplet. With the spatter rate closely related to the regularity of the arc and short-circuit time, the likelihood of spatter generated, therefore, is significantly greater when the short-circuit time or arc time is irregular [9]. From the pattern of the arc signals and by referring the instantaneous VI transient values the metal transfer modes were derived and given in Table 2. For fusion welding the heat input is an important characteristic because it influences the cooling rate greatly. The cooling rate is one of the important factors that determines the mechanical properties and metallurgical structure of the weld and the heat-affected zone (HAZ) [12]. At similar welding conditions, the mean arc power consumed by PESMAW process was found to be nearly the same as the mean arc voltage and current recorded nearly equal values as given in Table 2. However, the heat input- the ratio of the power consumption to the arc travel rate shows considerable increase in magnitude at low arc travel rates. As the arc travel rate reduced, the arc exposure time over the base metal surface increased, resulting in higher heat inputs. Moreover, the degree of increase in heat input was found to be more prominent at high current settings than it was at low current levels.

3.0 CONCLUSION

The transfer of droplets during the welding of E6013 covered electrodes in Plasma Shielded Metal Arc Welding (PESMAW) was evaluated by simultaneously recording arc voltage and current signals using a high-speed data acquisition system. The analysis of the 'VI' transients at real time indicated mixed mode of metal transfer that comprise substantial globular transfer to occasional spray and short circuiting transfer. The metal transfer behavior - mixed mode of predominantly globular transfer to occasional spray and short circuiting transfer was found to be consistent at both high and low current levels at constant arc travel rate. The occurrence of globular transfer is attributed to the orifice gas flow at low current range of 90-110A used in the investigation. Recording and Analysis of 'VI' (Arc voltage and current) transients in real time can be used as an effective tool to understand and study the mode of metal transfer occurs in arc welding processes.

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