INFLUENCE OF PROCESS PARAMETER ON THE CLAD SURFACE CHARACTERISTICS IN PULSED CURRENT GMAW PROCESS

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ABSTRACT

The clad surface characteristics, which have an important role on the clad quality, have been influenced by the parameters of pulsed current GMAW (GMAW-P) viz. peak current (Ip), peak duration (Tp), background current (I_B) and background duration (T_B) (Fig. 1). Selection of the most suitable combination of pulse parameters is very difficult due to the complex interdependence of the above parameters of pulsed current (1-4). To resolve this problem, studies have been carried out for different types of droplet detachments namely background detachment, one droplet detachment per peak, two droplets detachment per peak and three droplets detachment per peak by varying pulse cycle time. Effect of the GMAW-P parameters on clad surface characteristics has been studied. The suitable type of droplet detachment for cladding, using 1.2 mm diameter of ER 5356 filler metal, has been selected on the basis of uniformity in clad surface undulation. This is done to obtain good quality clad. For this a quantitative evaluation of the quality of clad was carried out by measuring the surface characteristics of the clad using a computerized measuring system based on a Linear Variable Differential Transformer (Sylvac). Fluctuations on the top of the clad surface were displayed numerically on the digital-indicating unit of a LVDT (1 micron accuracy). All the displayed digital output values were transferred to a personal computer through a data acquisition card and analyzed statistically to calculate the standard deviation (σ) and coefficient of variation (C.V.) of the same. Among these four types of droplet detachments, the lowest standard deviation (0.0553) and the lowest coefficient of variation (0.0252) were found for the clad made with one-droplet detachment during peak-per-pulse. Smaller the standard deviation and the coefficient of variation, the smoother the clad surface. Hence, one-droplet detachment per peak was considered to be capable of providing smoother clad surface than other types of droplet detachments. Based on this, the following parameters of the pulsed current were found to be more suitable than other combinations of pulsed current (Clad No.C4). I_P = 196.8 A; T_P = 5.0 ms; I_B = 20A; T_B = 6 ms; W_F = 6 m/min; I_{AV} = 99.7 A and W_S =10.0 mm/s. *The peak energy was found to be low for background detachments.*

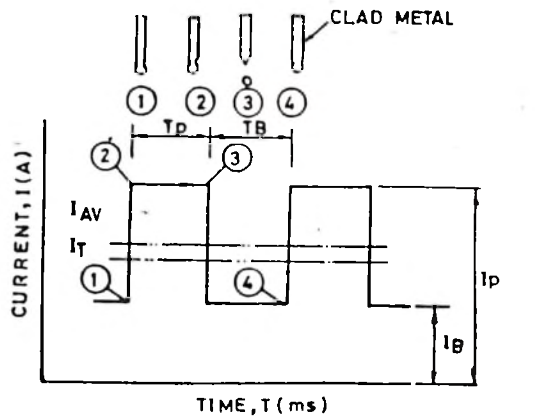
Keywords : Al-Mg Alloys Cladding, Droplet Detachment, Pulsed Current Gas Metal Arc Welding, Pulse Parameters, Clad Surface Undulation, Clad Characteristics, Clad Quality.

INTRODUCTION

Aluminium and its alloys are widely used in the transportation industry, where lightweight, corrosion resistance and high fatigue strength are the desired properties. Rolling, explosive welding or fusion welding commonly does the cladding. Fusion welding is readily accepted by an engineering industry due to its easy and versatile application and no legal implication of safety, pollution and noise. One of the fusion welding processes "Pulsed current gas metal arc welding process" (GMAW-P) is widely used to clad many components of spacecraft, automobile, ship, aircraft, railroad, bridges, oil tanks, pipe lines, structures, cryogenic storage tanks, marine, unfired pressure vessels, T.V. towers, missiles components and drilling rigs using Al-Mg alloys. Al-Mg alloys offer maximum resistance to atmospheric, salt water and alkaline corrosion (5). The GMAW-P may be considered a potential process for the cladding using Al-Mg alloys, where the dilution can be controlled more precisely than other conventional welding processes.

The pulsed current gas metal arc welding (GMAW-P) process has recently gained wide attention in welding industry, due to its comparatively low heat input and precise control over the thermal cycle (6). Because, in pulsed current gas metal arc welding (GMAW-P) process, spray transfer or more precisely controlled droplet transfer is obtained at low average current. This condition provides a smaller and controlled weld pool, which allows cladding of thin materials in all positions (2). Detachment of molten metal droplets from the filler metal, its transfer across the arc and its flow into the weld pool are defined as metal transfer characteristics. Droplet detachment characteristics are defined as (a) the size of molten droplet (b) instance and duration at which detachment takes place and (c) number of droplet detachments per pulse.

The superiority of the GMAW-P process is mainly related to the nature of metal deposition governed by the pulse parameters viz. peak current (I_p), peak duration (T_p), background current (I_B) and background duration (T_B)(7). Depending on the parameters of GMAW-P (Fig.1) process either a single droplet or multiple droplets may get detached. If it is a single droplet, this detachment may occur either in peak duration or background duration and if it is multiple droplet detachment, the same may occur in peak duration. This difference in the timing of droplet detachment affects the unifomity in clad surface undulation and overall quality of the clad (8). These characteristics have been investigated in this study. Experiments were conducted at fixed value of WF, I_B and T_B to establish the relationship between Ip and Tp for different types of droplet detachments namely background detachment, one droplet detachment per peak, two droplets detachment per peak and three droplets detachment per peak. In order to obtain the above type of droplet detachments, pulse cycle time is allowed to vary. For this, it was not assumed that the molten droplet diameter is equal to the diameter of clad metal. In addition to obtaining the above relationship between I_P and T_P, further studies have been carried out to select a suitable type of droplet detachment to obtain good quality clads.



Ip - Peak Current (A) I_B - Background Current (A)
T_P - Peak Duration (ms) T_B - Background Duration (ms)
T - Pulse Cycle Time (ms) $T=T_P+T_B$ Pulse Frequency, $F_{PU} = I/T$
I_{AV} - Average Current (A) $I_{AV} = (I_P\ T_P + I_B\ T_B) / (T_P + T_B)$
IT - Spray Current Level (A) 1,2,3 and 4 stages of metal transfer
Above I_T - Spray metal transfer
Below I_T - Globular metal transfer

Fig. 1 : Pulsed current metal transfer

Objective

The objective of this investigation was to determine the suitable combination of pulse parameters to obtain a good quality clad.

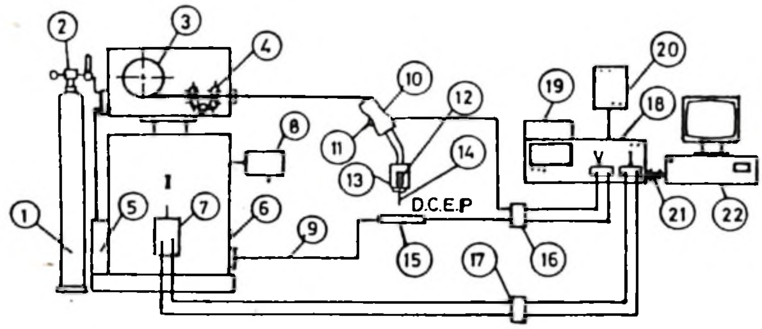
Experimental work

Materials

The cladding was carried out with a diameter of 1.2 mm ER 5356 Al-Mg wire. To study the clad surface characteristics of the ER 5356 Al-Mg alloy, cladding was done on the compatible AA 5083 Al-Mg alloy of 6.0 mm thickness base metal. Argon gas having a commercial purity of 99.97% and a flow rate of 20 L/min was used throughout the cladding as shielding gas.

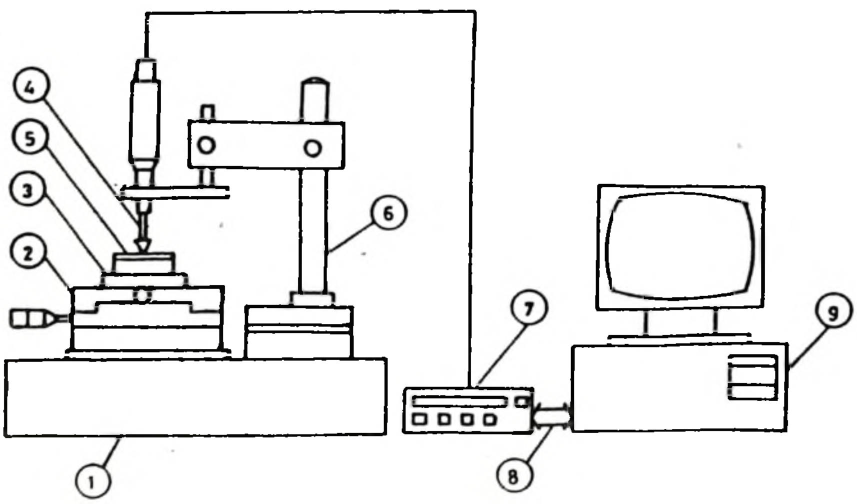
Cladding Equipment

Fig. 2 shows the schematic layout of the experimental set-up of GMAW-P. Transistorized welding power supply - Transarc Fronius 500 was used for carrying out cladding operations in pulsed current, operating with a constant voltage output characteristics. In pulsed current mode, peak voltage, background voltage, peak duration, cycle time and wire feed rate can be varied over a range of 10 to 40 V, 10 to 30 V, 1 to 15 ms, 3.3 to 50 ms and 0 to 18 m/min, respectively.



1) Argon gas cylinder
2) Regulator with flow meter
3) Clad metal reel
4) Clad metal feed rollers
5) Water cooling unit
6) Transistorized cladding power supply
7) RTR-B control PCB plug x 102
8) Power supply control unit for setting parameters
9) Workpiece lead
10) Torch
11) Torch switch
12) Contact Tip
13) Gas nozzle
14) Clad metal
15) Base metal
16) 5 KHz low pass passive filter for voltage signal
17) 5 KHz low pass passive filter for current signal
18) Double channel digital storage oscilloscope
19) Internal color digital plotter
20) Wave form processor
21) GP-IB interface
22) Personal computer

Fig. 2 : Experimental set-up of the pulsed current gas metal arc cladding



1) Base
2) X-Y measuring table with micrometer
3) Fixture
4) LVDT Probe (P 25)
5) Cladded workpiece
6) Measuring Stand
7) LVDT Digital indicating unit (D50)
8) Interface (PCL 208)
9) Personal computer

Fig. 3 : Schematic layout of the linear variable differential transformer (LVDT) experimental set-up to measure clad surface undulations.

Setting directly the levels at peak and background current is not possible in the above welding power supply. Hence, levels of peak and background voltage were adjusted by trial and error to obtain the desired peak and background current levels and they were measured using a high speed double channel digital storage oscilloscope. Wire feed rate, peak duration and cycle time could be independently adjusted using the power supply control.

Filters for Voltage and Current Signals

The problem of high frequency noise and process noise in the signals of voltage and current was discussed with the manufacturer of welding power supply (9) and eliminated from the signals using two 5 kHz low-pass passive filters as shown in Fig. 2. These filters permit frequencies below 5 kHz to pass and reject all other frequencies, which are above 5 kHz. Since expected molten droplet frequency is well within 5 kHz, droplet detachment phenomena could be clearly studied from the blips on the waveform of pulsed voltage.

Instrumentation

Currents during cladding were sensed from the RTR-B control PCB - plug x - 102 of cladding power supply (9) as shown in Fig. 2. Voltage levels were sensed between the base metal and the contact tip (10,11) and they are used as measure of arc voltage. Sufficient time was allowed during cladding to reach a stable cladding condition. For this, delay time was set in the oscilloscope and then instantaneous current and voltage were monitored and recorded simultaneously with a high speed double channel digital storage oscilloscope (Gould 4072) through 5 kHz low-pass passive filters (Fig. 2).

Levels of peak current were measured on the pulsed current waveform for every pulse cycle time and average peak current level was taken as a measure of peak current. Levels of background current were measured on the captured pulsed current waveform for every pulse cycle time and the average background current level was taken as a measure of background current. Droplet detachment was observed from the blips on the waveform of pulsed voltage. There are variations in the peak voltage values along peak duration except those due to the intentional pulsing. The reason for variations is that when the droplet is transferred, the instantaneous arc voltage will momentarily increase and form blips on the peak voltage levels along the peak duration (1, 12). Droplet detachment time and the number of droplet detachments were obtained from pulsed voltage traces.

The total area of the captured waveform of the pulsed current was measured by using a wave form processor of the oscilloscope. Average current was calculated by dividing the total area of the current waveform by total time duration, which corresponded to the measured area of the waveform. Similarly, average voltage was calculated by dividing the total area of the pulsed voltage waveform by the corresponding total time.

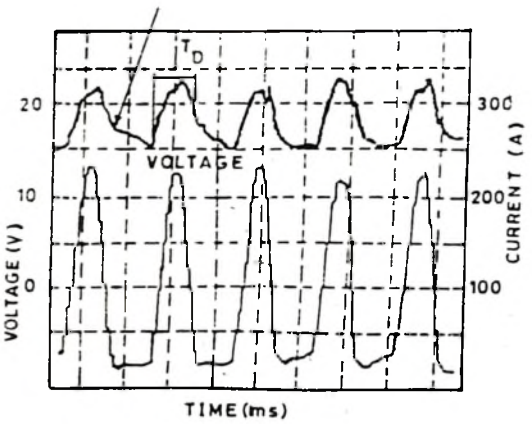
Welding Procedure

Clad metal was connected to the direct-current-electrode-positive (DCEP) polarity. Prior to cladding, the base metal surface was mechanically cleaned. Cladding torch was mounted on four-wheeled variable speed tractor (Esab A2 Mini trac). It was moved above the base metal and cladding was carried out (down hand type) in the rolling direction of base metal. The torch-to-work-angle was maintained at 90° and contact tip-to-work distance at 15 mm. Proper guiding was ensured and proper alignment was made for moving the variable speed tractor with cladding torch over the base metal. This set-up ensures constant gap between the contact tip and base metal throughout the cladding operation and this ensured that the current levels are the same throughout the length of a clad. The suitable parameters of the pulsed current and the type of droplet detachment to obtain good quality clads were selected on the basis of quality parameters viz. clad surface quality. Method of measurements of this quality parameter is detailed below:

Quality Parameters and their Measurements

A quantitative evaluation of the quality of clad was carried out by measuring the surface characteristics of the clad using a computerized measuring system based on a Linear Variable Differential Transformer (Sylvac) (Fig. 3). Workpiece was mounted on a X-Y measuring table using a specially designed and fabricated fixture. Workpiece was

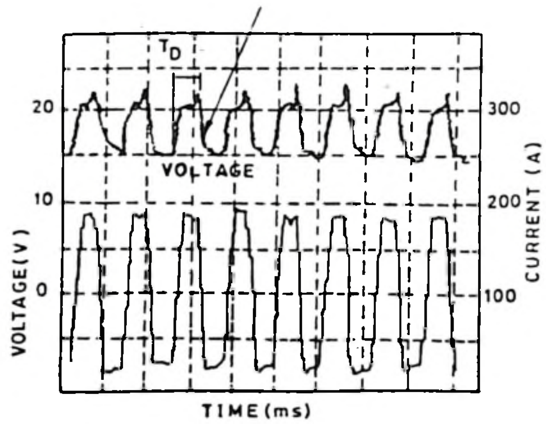
VOLTAGE SPIKE INDICATING DROPLET DETACHMENT



I_P = 240.5A ; T_P = 3.0 ms; I_B = 20A;
T_B = 6 ms (CLAD NO : C1);
Scale : X axis : 5ms/div;
Y axis : 5V/div and 50 A/div

Fig. 4 : Typical arc voltage and current traces indicating back ground detachment

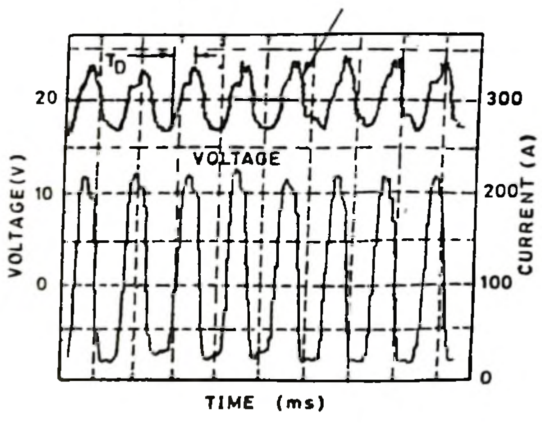
VOLTAGE SPIKE INDICATING DROPLET DETACHMENT



I_P = 196.8A ; T_P = 5.0 ms; I_B = 20A;
T_B = 6 ms (CLAD NO : C4);
Scale : X axis : 10ms/div;
Y axis : 5V/div and 50 A/div

Fig. 5 : Typical arc voltage and current traces indicating one droplet detachment

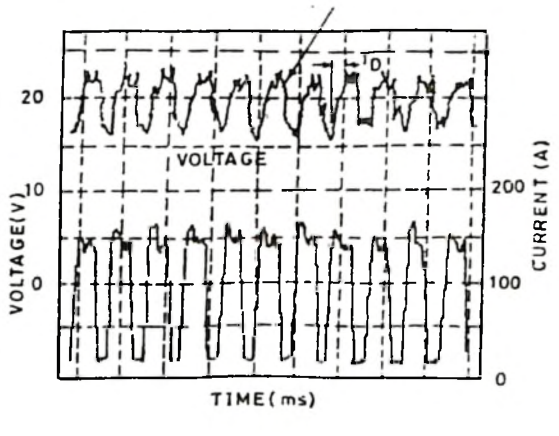
VOLTAGE SPIKE INDICATING DROPLET DETACHMENT



I_P = 230.3 A ; T_P = 5.0 ms; I_B = 20A;
T_B = 6 ms (CLAD NO : C6);
Scale : X axis : 10ms/div;
Y axis : 5V/div and 50 A/div

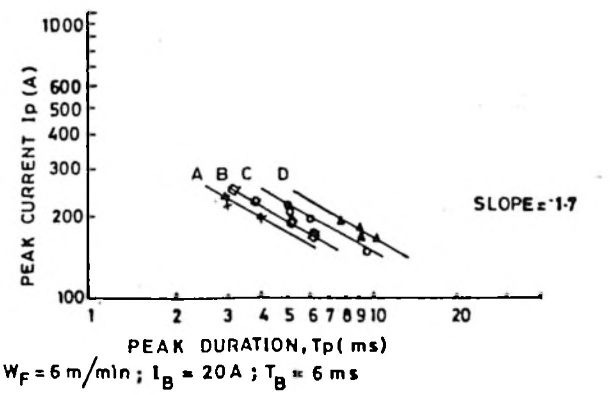
Fig. 6 : Typical arc voltage and current traces indicating two droplets detachment per peak

VOLTAGE SPIKE INDICATING DROPLET DETACHMENT



I_P = 172.7A ; T_P = 100 ms; I_B = 20A;
T_B = 6 ms (CLAD NO : C11);
Scale : X axis : 20ms/div;
Y axis : 5V/div and 50 A/div

Fig. 7 : Typical arc voltage and current traces indicating three droplets detachment per peak



Type of droplet detachment		Relationship	
A -	Background detachment	$I_P^{1\text{-}7}\ T_P$	$= 34\ A^{1\text{-}7}\ S$
B -	One droplet detachment per peak	$I_P^{1\text{-}7}\ T_P$	$= 40\ A^{1\text{-}7}\ S$
C -	Two droplets detachment per peak	$I_P^{1\text{-}7}\ T_P$	$= 50\ A^{1\text{-}7}\ S$
D -	Three droplets detachment per peak	$I_P^{1\text{-}7}\ T_P$	$= 62\ A^{1\text{-}7}\ S$

Fig. 8 : Relationship between I_P and T_p for different types of droplets detachments

aligned properly and moved under a LVDT probe, in the direction of cladding. LVDT probe with a standard contact point of 2 mm diameter carbide ball was used (Fig. 3). A sample length of clad used was 25 mm. Transistorized welding power supply-Transarc Fronius 500 was used for carrying out cladding operations. Fluctuations on the top of the clad surface were displayed numerically on the digital-indicating unit of a LVDT (1 micron accuracy). All the displayed digital output values were transferred to a personal computer through a data acquisition card and analyzed statistically to calculate the standard deviation (σ) and coefficient of variation (C,V) of the same. The clad surface undulation profile with lesser standard deviation and coefficient of variation was considered to be good from the point of view of smooth clad.

Results and Discussion

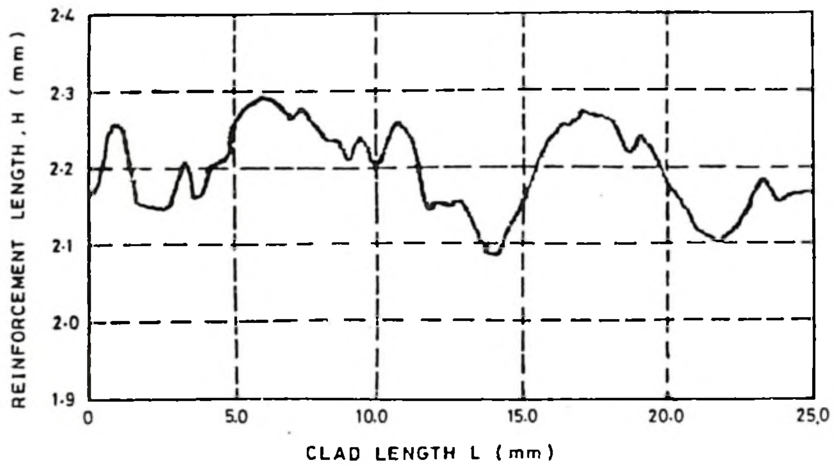
Limiting Peak Current (I_p) and Peak Duration (T_p)

Experiments were conducted at fixed value of W_F = 6 m/min, I_B = 20 A and T_B = 6 ms to establish the relationship between I_P and T_P for different types of droplet detachments namely background detachment, one droplet detachment, two droplets detachment and three droplets detachment per peak, respectively (13). For this, levels of I_P were kept above the spray current level (14-17), and I_P and T_P were allowed to vary (Figs. 4-7). In order to obtain the above types of droplet detachments, pulse cycle time was allowed to vary. For this, it was not assumed in this study that molten droplet diameter would be equal to the diameter of clad metal.

The values of I_P and T_P were grouped according to the type of droplet detachment and plotted on the logarithmic scale (Fig. 8). Slope between I_P and T_P was found to be -1.7 for all types of droplet detachments i.e. $T_P \ \alpha \ I_P^{-1.7.}$ Amin (1) found the slope as -2.3 for 1.6 mm diameter of pure aluminium filler metal, and Trindade and Allum (13) found the slope as -2.0 for the filler metal diameter of 1.2 mm, pure aluminium. However, Araya, Endo, Imamiya, Ando and Sejima (18) found the slope as -1.54 for the filler metal diameter of 1.6 mm, ER 4043 Al-Si alloys. This shows that the slope varies depending on chemical composition and diameter of filler metal. The relationship between I_P and T_P can be expressed can be expressed as follows :

$$Ip^{1.7}\ T_P = K_V \quad A^{1.7}\ S \qquad ...1$$

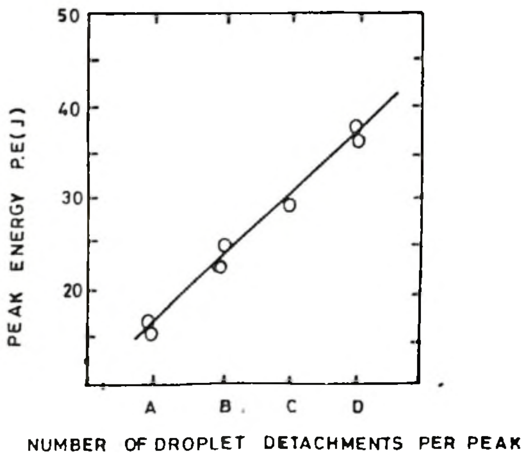
Where Kv is a constant called detachment parameter. The values of constant vary depending on the droplet volume to be detached from a given filler metal and diameter. In this investigation, Al-Mg alloy clad surface characteristics, produced by the GMAW-P process were studied with respect to the pulse parameters viz. peak current (I_p), peak duration (T_p), background current (I_B) and background duration (T_B).



Maximum value : 2.077 Standard deviation : 0.0553
Maximum value : 2.292 Coefficient of variation : 0.0252
Arithmetic mean : 2.197

I_P = 196.8; T_P = 5ms; I_B = 20A; T_B = 6.0ms
WF = 100mm/s; Ws = 10.0mm/s

Fig. 9 : Typical clad surface undulation recorded by LVDT (Clad No.C4)



A - Background detachment
B - One droplet detachment per peak
C - Two droplets detachment per peak
D - Three droplets detachment per peak

Fig. 10 : Relationship between peak energy and number of droplet detachments per peak

Selection of Suitable Pulse Parameter Combinations and suitable Type of Droplet Detachment

Clad surface undulation criterion has been considered for selection of the suitable pulse parameter combinations in order to obtain good quality clad. Also, on the basis of the above criterion, the suitable type of droplet detachment was recommended among the four different types of droplet detachment viz. background detachment, one droplet detachment, two droplets detachment and three droplets detachment per peak (Figs. 4-7) (per peak is applicable only to one droplet detachment, two droplets detachment and three droplets detachment).

Uniformity in Clad Surface Undulation

Typical clad surface undulation as revealed by LVDT traverse is shown in Fig. 9. The standard deviation and the coefficient of variation of the clad surface undulation were calculated for four types of droplet detachment, which were produced at various combinations of pulsed current, viz. background detachment, one droplet detachment per peak, two droplets detachment per peak and three droplets detachment per peak and given in Table 1. The lowest standard deviation and the lowest coefficient of variation were observed for the clad nos. C 1, C 4, C 6, and C 11 which were produced at different welding conditions viz. background detachment, and one droplet detachment, two droplets detachment and three droplets detachment per peak, respectively. Among these four types of droplet detachment, the lowest standard deviation (0.0553) and the lowest coefficient of variation (0.0252) were found for the clad made with one droplet detachment per peak (Clad No. C4). Smaller the standard deviation and the coefficient of variation, the smoother the clad surface. Hence, one droplet detachment per peak was considered to be capable of providing smoother clad surface than other

Table 1 : Types of droplet detachment, and Statistical Analysis of Weld Bead Surface Undulation

Clad No.	Ip (A)	Tp (ms)	(a) I_{AV} (A)	(a) V_{AV} (V)	TY	CSU	P.E. (J)
C 1	240.5	3.0	96.0	18.6	A	0.0611(c) 0.0283(d)	16.7
C 2	211.5	4.0	96.4	19.1	A	0.0714 0.0334	19.5
C 3	226.0	4.0	101.8	18.2	B	0.0616 0.0300	21.3
C 4	196.8	5.0	99.7	18.1	B	0.0553 0.0252	22.5
C 5	180.5	6.0	99.4	18.6	B	0.1540 0.0657	24.7
C 6	230.3	5.0	109.4	18.3	C	0.0756 0.0352	26.5
C 7	207.8	6.0	109.5	18.3	C	0.0976 0.006	29.6
C 8	160.0	9.0	105.7	18.7	C	0.0792 0.0320	32.8
C 9	192.9	8.0	109.8	19.9	D	0.0736 0.0291	36.9
C 10	180.2	9.0	109.2	19.6	D	0.0992 0.0432	38.3
C 11	172.7	10.0	104.6	20.2	D	0.0740 0.0318	40.8

(a) : Measuring value
(b) : Average value
(c) : Standard deviation
(d) : Coefficient of Variation
I_B = 20A W_F = 6m/min
T_B = 6 ms W_S = 10 mm/s

TY : Type of droplet detachment
A : Background detachment $Ip^{1.7}$ Tp = 34.0 $A^{1.7}$.s
B : One droplet detachment per peak $Ip^{1.7}$ Tp = 40.0 $A^{1.7}$.s
C : Two droplets detachment per peak $Ip^{1.7}$ Tp = 50.0 $A^{1.7}$.s
D : Three droplets detachment per peak $Ip^{1.7}$ Tp = 62.0 $A^{1.7}$.s
P.E : Peak Energy = Ip x Tp x Vp (J)
C.S.U. : Clad Surface Undulation

types of droplet detachment. Based on this, the following corresponding parameters of the pulsed current were found to be more suitable than other combinations of pulsed current. I_p = 196.8A; T_p = 5.0ms; I_B = 20A; T_B = 6ms; W_F = 6m/min; I_{AV} = 99.7A and W_S = 10.0mm/s. However, standard deviation and coefficient of variation of the clad made with background detachment (Clad No. C 1) was found to be second in the order of smooth clad surface.

Peak Energy

The peak energy was determined for the various droplet detachment conditions and given in Table 1 Results show that the peak energy required for background detachment is less but the peak energy required for other types of droplet detachment is high. The reason is that the combination of the highest I_P and the lowest T_P is used during background detachment and results in low peak energy. Hence, background detachment is preferable (Fig. 10).

CONCLUSIONS

The most significant findings of this study can be summarized as follows

1. The slope between Ip and Tp was found to be 1-7 for all types of droplet detachments i.e. Tp α $Ip^{-1.7}$. Slope varies depending on chemical composition and diameter of clad metal. The relationship between Ip and Tp can be expressed as follows :

   $Ip^{1.7}$ Tp = Kv $A^{-1.7}$ S

   Where K_V is a constant called as detachment parameter. The values of constant vary depending on the droplet volume to be detached from a given clad metal and diameter.

2. A smoother weld surface was observed for the welds made with one droplet detachment per peak (Clad No C 4) than background detachment, two droplets detachment per peak and three droplets detachment, per peak conditions.

3. Peak energy required for background detachment is less but one droplets detachment per peak, two droplets detachment per peak and three droplets detachment per peak conditions require high peak energy.

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NOMENCLATURE

C.V.	Coefficient of Variation
DCEP	Direct Current Electrode Positive
I	Welding Current
I_B	Background current
I_P	Peak current
I_{AV}	Average current
K_V	Detachment parameter
LVDT	Linear Variable Differential Transformer
Mg	Magnesium
GMAW-P	Pulsed Current Gas Metal Arc Welding
T	Pulse Cycle Time
T_B	Background Duration
T_D	Droplet Detachment Time
T_p	Peak Duration
V	Voltage
V_B	Background Voltage
V_D	Droplet Volume
V_p	Peak Voltage
V_{AV}	Average arc voltage
W_F	Clad Wire Feed Rate
W_s	Cladding Speed
σ	Standard Deviation