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Pulsed GMAW : One-Drop-Transfer and Process Parameter†

Fukuhisa MATSUDA*, Masao USHIO, Yasuhiro TANAKA***, Keiji ITONAGA****, and Takashi YOKOO*******

Abstact

Metal transfer behavior and its relation to process parameter in pulsed GMA welding (GMMA and CO_2 Welding) are investigated by using the square wave current. Particularly, the process parameters which enable the stable one-drop-transfer per pulse are experimentally obtained with various shielding gases. Argon(80%)−CO_2(20%) mixture gas and CO_2 (100%) gas are mainly used and the differences in metal transfer mode are discussed. With Argon(80%)−CO_2(20%) mixture gas, the stable transfer is obtained by detaching the drop from the wire end at the end of higher current phase or during the following base current phase. With CO_2 (100% ~ 50%) the metal is stably transfered in the arc space when it is detached just during the higher current phase. The regions of process parameter of stable pulsed GMA welding are specified, related with the difference in detaching behavior.

KEY WORDS: (Pulsed GMMA Welding) (Pulsed GMA Welding) (MIG Welding) (GMA Welding) (CO_2 Welding) (MAG Welding) (Metal Transfer)

1. Introduction

The underlying concept of metal transfer in pulsed GMA welding is to transfer one drop per pulse. This comes mainly from the requirements of regularity and stability of metal transfer. On the otherhand, the pulsed current in the arc welding has another important possibility to control the work by various physical forces on metal transfer, arc behavior and weld pool.

In pulsed GMA welding with shield of Argon or Argon mixture gas including small amount of CO_2, the detaching of drop in higher current phase is followed by the sparay transfer comprising the continuous projection of a series of small droplets above the threshold current of transition of metal transfer mode, and consequently the occurrence of spattering by short-circuiting of prolonged sharp cone of molten wire. In this situation the stable one-drop-transfer can be obtained under the condition that a drop is formed at the wire end in the higher current phase and detached at the end of higher current phase or at a time in the following lower current phase[1,2]. However, if the metal transfer mode is grobular one like that in CO_2 arc welding, the detachment of drop should occur only during the higher current phase[3].

The stable and regular detaching of drop in CO_2 welding is very difficult in usual condition of welding. In the case of open arc condition of CO_2 welding, the spatter is more due to the strong repelling force of arc. However, if the detaching is raised before the arc force attacks the molten drop which is at the wire end, the stable and regular metal transfer should be obtained. Moreover it is expected it will reduce the spattering, too. It is considered to possible by applying the pulsed current suitably.

One-drop-transfer phenomena have variable features according to the pulsed current parameters such as peak current (higher current), base current (lower current), peak current duration, base current duration and pulse slope or shape, shielding gas composition, wire materials and wire feeding rate. Recently, Allum, C.J. has precisely analyzed the relation between one-drop-transfer condition and pulse current parameter in MIG welding, particularly on heat content of drop[4]. The work described here verifies the existence of preferable condition of pulse parameter for stable pulsed CO_2 arc welding, which enables to reduce the spattering extremely by using the transfer

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mode of one-drop-transfer. And also the metal transfer behavior of pulsed CO_2 welding and the effect of shielding gas composition on process parameter of one-drop-transfer are shown and discussed.

2. Wire Melting rate

All experiments were performed under the condition T_P(peak current duration) = T_B(base current duration) in the rectangular wave current shown in **Fig. 1**, by using a

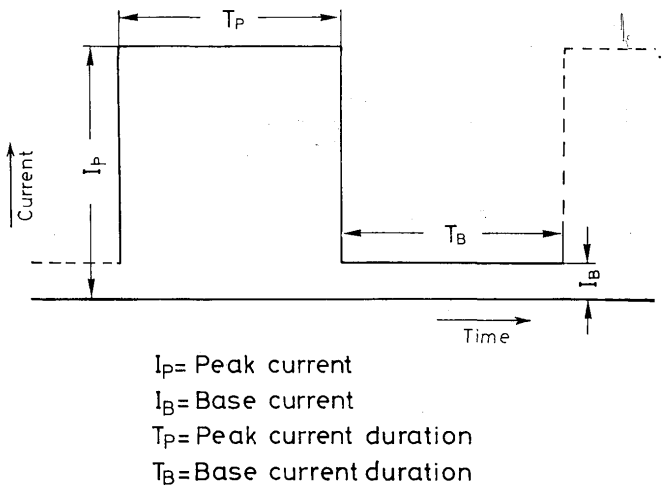


Fig. 1 Terminology of unit pulse.

transistorized pulse power source with constant current mode and electrode-positive polarity. A high speed cinecamera was used to observe the metal ttansfer phenomena and arc behavior[1]. Bead on plate welding was carried on by the use of mild steel wire and plate.

A universal relationship among the welding current, wire extension length and wire melting rate in steady current MIG welding is shown as follows[5,6],

$$v_W = AI + BLI^2 \quad , \qquad (1)$$

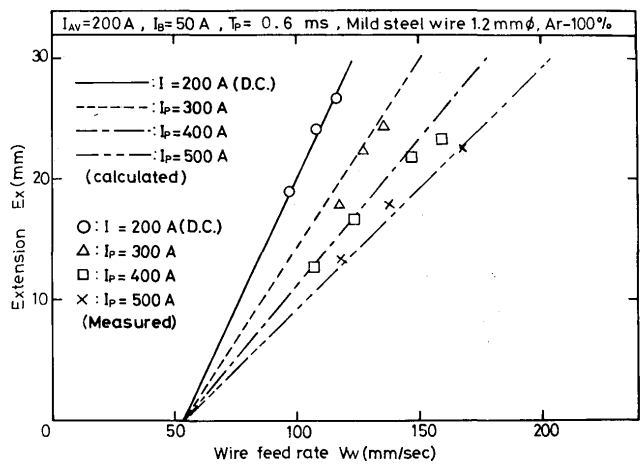


Fig. 2 Effect of peak current Ip on wire melting rate (I_{av} = 220 A).

where, v_W: Wire melting rate per second, I: Welding current and L: Wire extension length. For square wave current, above equation can be available. This means that for longer extension, pulsed current welding require the high speed feeding of wire and its tendency increases with the increase in peak current due to the effetiveness of joule heating shown in **Fig. 2**. Consequently the allowable range of wire feed rate to maintain stable open arc operation becomes wide. In other words, the wire feed rate is also an important process parameter to specify the one-drop-transfer condition[1].

3. One-Drop-Transfer in Mixture Gas Shielding

As stated above, in pulsed current welding of mild steel in argon shielding with small addition of CO_2 (below 20%), the difference between the first and subsequent detachments exists when it occurs during the peak current duration. Therefore, it is more stable to make detaching just at the end of peak current phase or during the base current phase. **Figure 3** shows the example of one-drop-

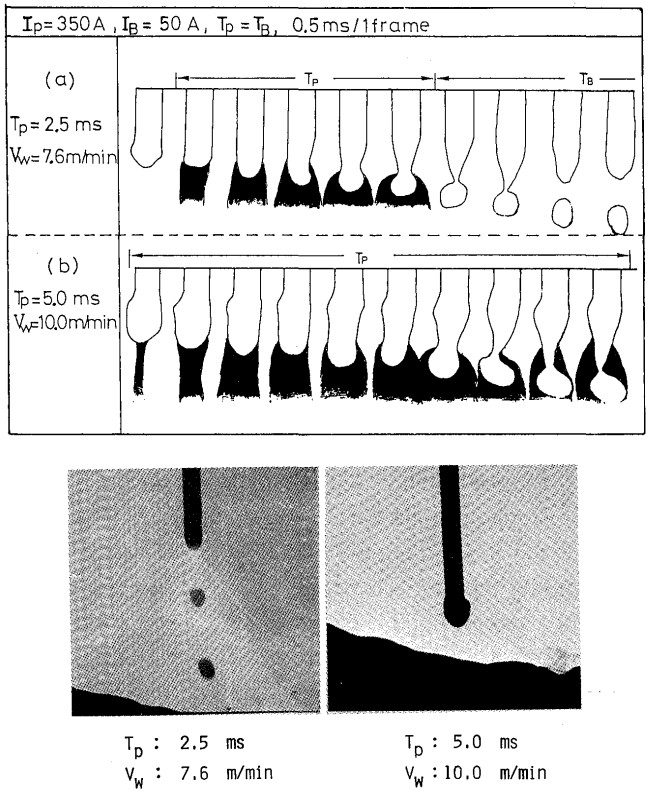


Fig. 3 Differences in time-variation of arc and wire tip shape under following conditions,
a) short wire extension, slow feed rate, T_P = 2.5 msec, v_W = 7.6 m/min.,
b) long wire extension, higher feed rate, T_P = 5.0 msec, v_W = 10.0 m/min.

transfer during base current phase for different two feed rates but same averaged currents. It manifests the change

in feed rate and pulse frequency gives the change in drop size, shown in the **Table 1**. The hatched area in **Fig. 4** represents some examples of the zone of stable operation of one-drop-transfer per pulse under the condition of $T_P = T_B$, I_B = 50 A, I_P = 300, 350, 450, A, Ar(80%)–CO_2 (20%) shielding and 25 mm in length between contact tip and plate.

T_p(ms)	Drop radius (mm) Maximum	Minimum	Drop volume(mm^3) Maximum	Minimum
2.5	0.58	0.54	0.82	0.66
3.0	0.64	0.58	1.10	0.82
4.0	0.71	0.67	1.50	1.26
5.0	0.78	0.75	2.00	1.77
5.5	0.80	0.79	2.15	2.01

Table 1. Maximum and minimum sizes of drop in variable T_P. I_P : 350 A, I_B : 50 A, $T_P = T_B$, Ar(80%)–CO_2(20%).

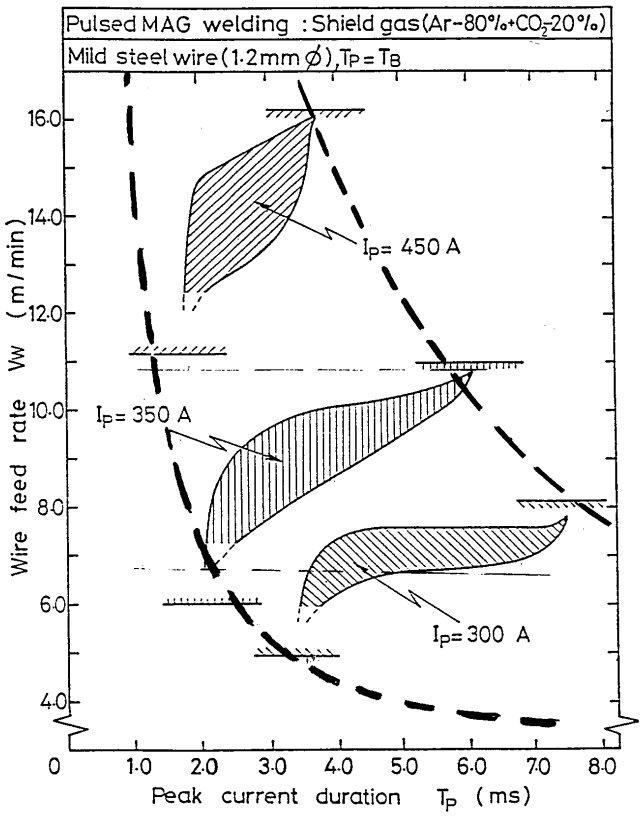


Fig. 4 Effect of peak current value on the variation of zone of stable one-drop-transfer per pulse.

4. One-Drop-Transfer in Pulsed CO_2 Arc Welding

In CO_2 arc welding successful open arc operation is very difficult due to repelling by the arc. Very frequently the drops detach in an upward or sideward direction. Therefore, to obtain effective transfer to the weld pool it

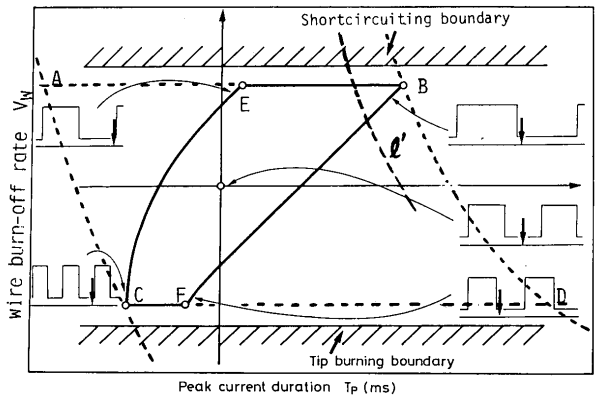


Fig. 5 Diagram representing the contour of zone of stable one-drop-transfer.

is necessary to use short-circuiting transfer. But, the short-circuiting transfer has essentially a serious disadvantage, spattering of molten metal.

There are two types of spattering in short-circuiting transfer CO_2 welding. These are the one related to short-circuiting of molten wire and weld pool, and the other independent of metal transfer phanomena. The most serious spattering among former phenomena is the spattering of weld pool metal due to the mechanical arc force which abruptly increases in downward direction associated with the break of short-circuiting. This could be overcome by operating it in open arc condition and by the use of suitably designed pulse current form.

Figure 6 shows an example of one-drop-transfer

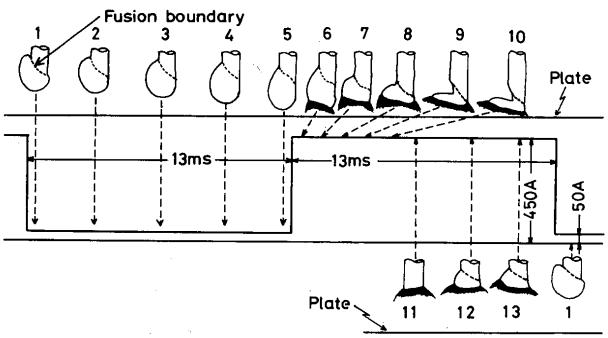


Fig. 6 Example of drop transfer behavior in pulsed CO_2 welding.

behavior in pulsed CO_2 arc welding. The figures of arc and drops are sampled from high speed cine-films taken with 3000 frames/sec. This detaching and transfer phenomena are different from those of pulsed GMA welding with argon(80%)–CO_2(20%) mixture shielding gas. The drops detach regularly only in the early stage of high current phase. The detaching in the base current phase is very difficult to realize with CO_2 shielding gas. This difference in one-drop-transfer behaviors with various gas compositions has close corelation to the one in steady current welding.

In pulsed CO_2 arc welding, after the detachment of

drop, the wire is continuously molten by the peak current and a large molten drop is formed at the end of wire. This drop is pushed up along the wire due to the strong arc force in T_P phase, but in the fllowing T_B phase it begins to slide downward by the decrease in arc force and subsequently hung on the wire end. As restaring the peak current, it rapidly detaches from the wire end and is transfered to the weld pool. Process parameter of one-drop-transfer is shown in **Fig. 7**.

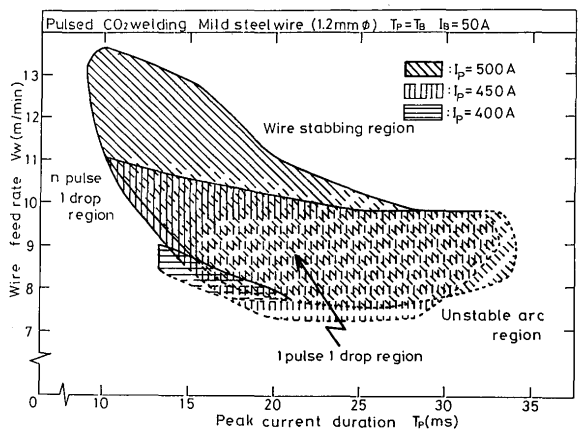


Fig. 7 One-drop-transfer condition of pulsed CO_2 welding for the variable Ips, (Ip : 400, 450, 500 A).

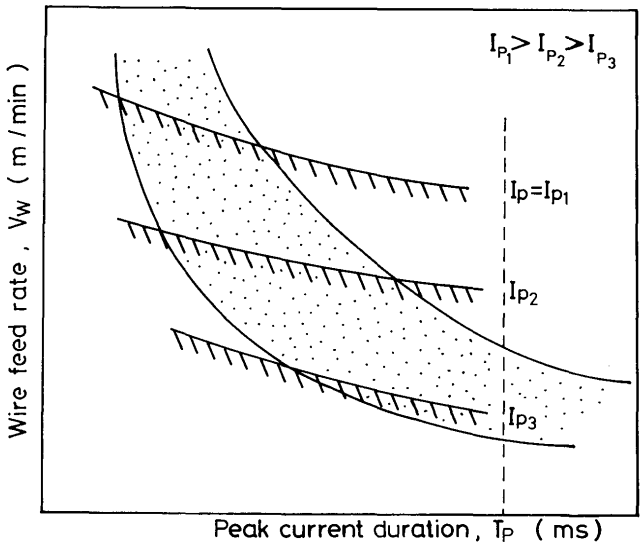


Fig. 8 Diagram representing the contour of one-drop-transfer parameter zone.

Figure 10 shows the relation between T_P and the detechment time T_D under the condition of one-drop-transfer. The detachment time T_D means the time required for detaching from the beginning of peak phase of pulse current as shown in **Fig. 6**. This result shows time duration of pulsed current T_P has no effect on T_D. Even if long T_P should be applied for a I_P value, the detachment time T_D will be constant. It suggests the detaching has a strong dependence on I_P value.

Figure 11 shows the relation between the pinch force ($\propto I^2$) and the detachment time T_D. This shows the detaching is mainly due to the pinch force.

Figure 12 represents the reduction of spatter by the use of CO_2 plused welding. By adjusting the pulse condition to the one-drop-transfer mode, the spattering was extremely reduced. The ratio of spattering in pulsed CO_2 welding to the one in ordinally used CO_2 arc welding reached to 1/5 in the optimum condition. This suggests there are very suitable pulse parameter which enables to reduce the spattering extremely even in short-circuiting transfer mode.

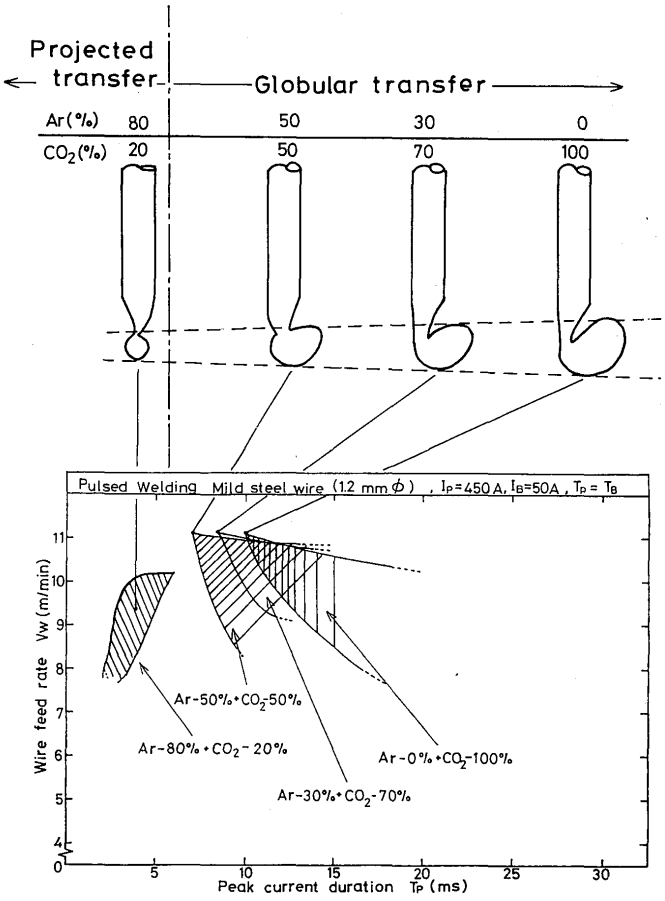
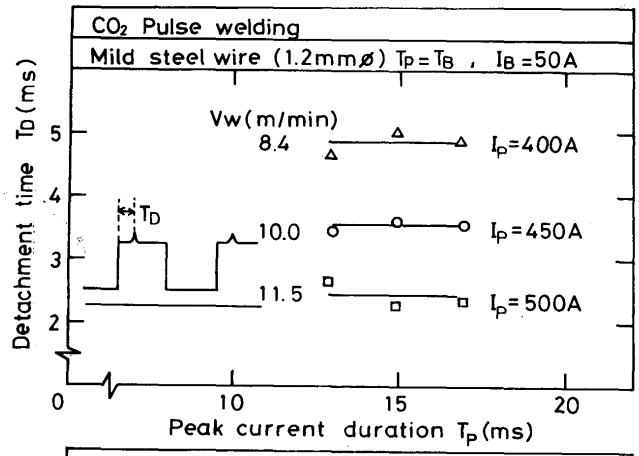


Fig. 9 Variations of preferable condition area of one-drop-transfer and corresponding drop size.

5. Discussions

Process parameter zone of one-drop-transfer shown in Fig. 4 and Fig. 7 can be explained as follows. When the conditions of $T_B = T_B$ and constant averaged current are adopted, the burn-off volume per pulse represented as $V_P = 2v_W/T_P$. As the drop size must be specified in a limited range, one-drop-transfer condition is in a area bounded by two hyperbolae on v_W-T_P diagram as shown in **Fig. 5** and **Fig. 8**.

In pulsed CO_2 welding, residual restrictive conditions



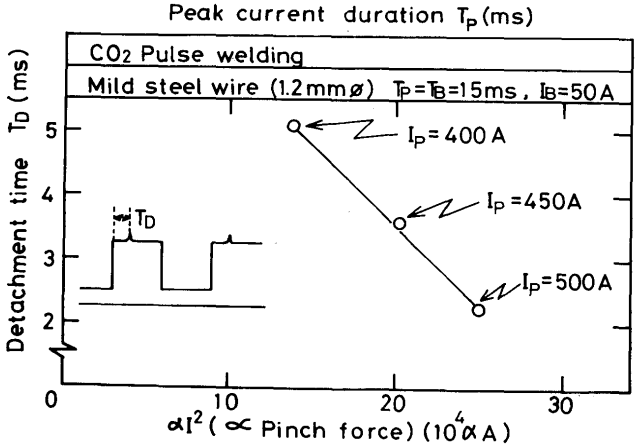


Fig. 10 Detachment times for various Ip values.
Fig. 11 Relation between pinch force (I_P^2) and detachment time.

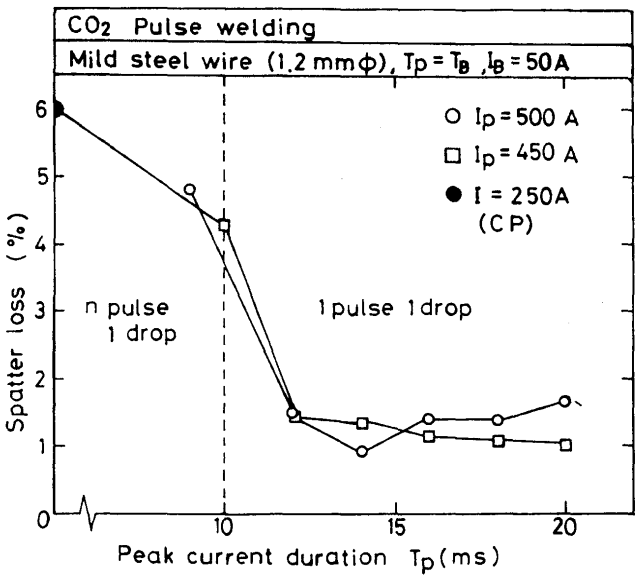


Fig. 12 Reduction of spatter by use of pulsed CO_2 welding.

specifying the area are the limited length of arc, those are, tip burning boundary and short-circuiting boundary. These two conditions are expressed by two horizons slightly coming down. The short-circuiting boundary has a dependence on peak current value I_P as easily derived from Eq. (1). A dashed perpendicular line represents the boundary above which the pertubation of molten pool becomes large and unstable. It might be related to the oscillation of weld pool metal. One-drop-transfer conditions illustrated in Fig. 7 is correspondigly explained by the Fig. 8.

As increasing the content of argon in CO_2 shielding gas, the drop size can be decreased as shown in **Fig. 9**. The lower limit in T_P adoptable for one-drop-transfer, therefore, shifts to the lower side in T_P.

Transition in transfer behavior between the grobular transfer to the projected one occurrs at the mixture condition around argon(70%)–CO_2(30%) in steady current welding. Thereby, as stated above, stable transfer is very difficult with this condition of shielding gas even in pulsed current welding.

In the lower region on CO_2 content below 20% one more other requirement is necessary to specify the one-drop-transfer condition. Namely the detaching must be caused in the time duration between the end of peak current phase and the end of subsequent base current phase. Figure 5 illustrates a diagram to explain the contour of the one-drop-transfer zone on the Fig. 4. Two hyperbolae which represent the constant drop size enclose an area ABCD with short-circuiting boundary and tip burning boundary. AC is a minimum drop size line on that the detaching may occur at the end of base phase T_B, and on BD the detaching will be expected to occur at the end of peak phase T_B. Because, as increasing T_P, the instance of detaching becomes earlier. On the otherhand, if T_P is decresed, the detahching must be delayed. As an example, we will consider the condition expressed by point B. At this point the detaching will occur just at the end of T_P phase. What will be happen, if we take a smaller drop size condition which is illustated by the curve ℓ'? In the case the allowable maximum T_P value must be lower than the value represented by point B, because the time duration necessary for detaching must be short. Therefore, the upper limit of T_P line becomes BF. Similarly the lower limit allowable to T_P is specified by the curve CE.

Above explanation on one-drop-transfer condition is complimentary to the assumption that the driving force acting on detaching is governed by the pinch force of I_P current. However the experimental results shown in Fig. 4 and Fig. 7 are considered to confirm the above explanation. In pulsed CO_2 welding the detachment time illustrated in Fig. 10 has no influence of T_P but strong corelation with pinch force as shown in Fig. 11.

6. Summary and Conclusions

Process parameter specifying the one-drop-transfer per

pulse in pulsed GMA welding of mild steel are experimentaly obtained and discussed. The effects of shielding gas composition on pulse parameter of one-drop-transfer are also invesigated by using argon-CO_2 mixture gas, and shown there are some differences in the transfer mode and drop size between the pulsed CO_2 welding and the pulsed gas mixtuer metal arc welding. With argon(80%) $-CO_2$(20%) mixture gas, the stable transfer of one-drop per pulse could be realized in a way that the detaching is caused at the end of peak phase or during base phase. With more than 30% of CO_2 content in argon shielding gas the detaching occur only during peak phase.

The preferable condition of pulsed CO_2 welding in the open arc operation was also investigated and shown clearly that it enables to reduce the spatter extremely.

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