Pulsed GMAW†

– Spattering in Pulsed CO_2 Welding –

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Abstrast

In order to reduce the spattering in CO_2 arc welding, a pulsed current is applied.

It is shown that a simple rectangular-wave pulse current can give a successful operation in the open arc situation and the spatter loss is decreased to $\sim 1/5$ in comparison with that in the usual CO_2 arc welding.

Three types of spattering process mainly occurred in the pulsed CO_2 arc welding are examined. The spatter ejected from the molten pool independent of the transfer phenomena, is extremely suppressed by Ti element included in the wire. Remaining two types of spatter are the one caused by Kink instability of the molten wire occurred at the instant of detachment of drop, resulted from the asymmetry of current path, and the other that a part of molten metal drop is blown off by the arc force.

Three-stage-wave pulse current is applied to decrease the welding current at the instant of detachment of drop, but spatter loss can not be suppressed extremely.

The shortcircuiting transfer combined with rectangular-wave pulse current is examined. Spattering is hardly occurred in the successful operation in which the shortcircuiting transfer from wire to the weld pool is limited to occur in the phase of low current.

KEY WORDS: (Pulsed GMMA Welding) (Pulsed GMA Welding) (CO_2 Welding) (Metal Transfer) (Spattering) (Dip Transfer)

1. Introduction

CO_2 welding has a conspicuous merit compared with other welding processes, inexpensive. But it has a disadvantage, too, spattering, which is awkward in automatic welding. One of the effectual means to reduce the spattering is to adopt the current control to the metal transfer process[1)].

In the GMA welding using Ar(80%)-CO_2(20%) mixture gas as shielding gas, the stable transfer of metal drops without spattering can be made by applying a pulsed current for the welding current. The synchronization between current pulsating and detaching of drop from the wire electrode is necessary and is established by adjusting the pulsed current parameters to proper range matched with the feed rate of wire in a given torch stand-off distance[1–4)].

Usually in CO_2 arc welding successful open arc operation is very difficult, because the detaching of drop to the upward or sideward direction may occur due to very strong repelling force of arc. It is possible to suppress the repelling force to the lower value by limiting the current to the adequate value. By applying the pulsed current to the CO_2 arc welding in open arc situation, one-drop transfer per pulse is realizable and the metal drop can be transferred rather stably to the weld pool in the arc space. In a previous paper, an example of the behavior of one-drop transfer in pulsed current CO_2 arc welding was shown, which allowed the occurrence of spattering to be very less[1)].

Spattering occurred in CO_2 arc welding has many mechanisms. The most serious spattering is the one associated with the metal transfer phenomena. In the case of pulsed CO_2 arc welding in open arc condition, the current in the instant of detaching of metal has a strong influence on the spattering phenomena. Besides pulse current parameter, content of chemical element in the wire like Ti has an influence on the behavior of molten part of wire, and therefore on the spattering phenomena. In the paper described here, continuously to the previous

† Received on May 31, 1985

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Transactions of JWRI is published by Welding Research Institute of Osaka University, Ibaraki, Osaka 567, Japan

paper, effects of above mentioned factors on the spattering are investigated.

Applying the pulsed current to the shortcircuiting transfer CO_2 arc welding is also considered to be possible, though the successful condition were limited in the very narrow range due to the irregularity in shortcircuitting between wire electrode and molten pool. It is also examined in this paper.

In consequence the purpose of the paper is to observe the dynamics of spattering and to present the effects of process parameter of pulsed current and Ti content in wire on the spattering and the suggestions to develop the spatter-less CO_2 arc welding.

2. Experimental Procedures

For all experiments in this paper, common welding conditions were used, shown in **Table 1**. Schematic appearance of experimental setup is shown in **Fig. 1**. Rectangular waveform is mainly used for welding current illustrated in **Fig. 2**, while three-stage waveform current is also applied as a part. Terminology of pulsed current is shown in Fig. 2.

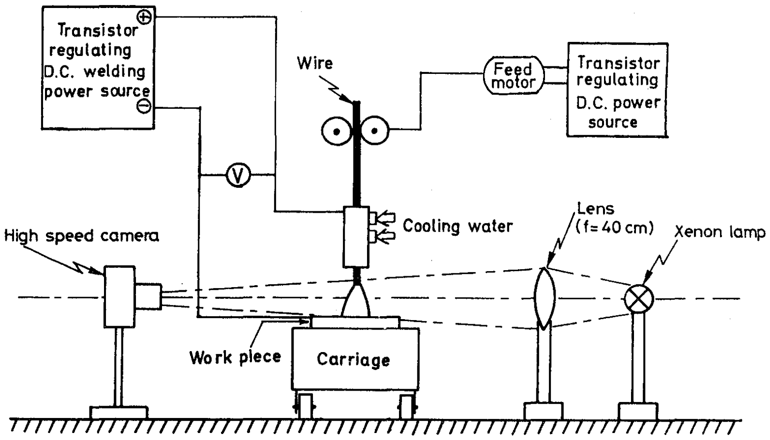

Fig. 1 Experimental set-up and procedure to collect spattered particles.

Table 1 Common welding conditions used.

Polarity	:	D.C.E.P.
Shielding Gas	:	CO_2 (25L/min.)
Wire	:	1.2 mm in Diameter, Mild Steel
Torch Stand-off Length	:	20 mm (Contact Tip-Plate)

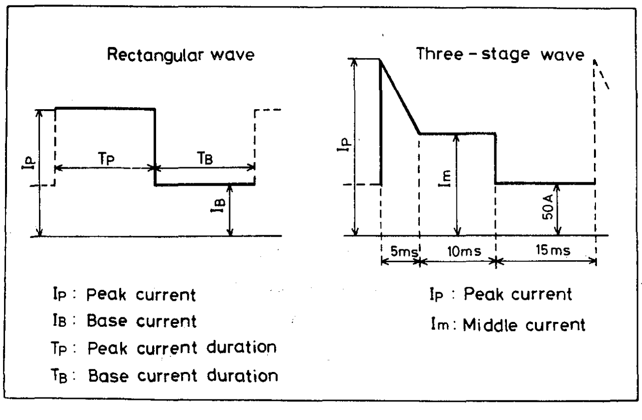

Fig. 2 Terminology of pulsed current applied.

Dynamic behavior of spattering was observed by taking high speed cine-pictures with 3000 frames/sec using a Xenon lamp as a backing light. Spattered particle was gathered by using a copper box which surrounds welding torch and work piece. Bead-on-plate welding of 25 cm in length was done in the copper box and after welding the weight of spattered particle was measured.

$$\text{spatter loss} = \frac{\text{weight of particles spattered}}{\text{weight of wire electrode used}}$$

Table 2 shows chemical compositions of materials used in the experiment. Wires are classified in two groups, namely, Ti-rich wires, A, B, and C, and the others, D, E.

3. Observation of Spattering in Pulsed CO_2 Arc Welding

An example of one-drop-transfer behavior in the pulsed CO_2 arc welding is shown in **Fig. 3**. The drop detaches regularly only in the early stage of the high current phase of pulsed welding current. In the voltage waveform there is a steep spike representing the detaching of drop. After detachment of the drop, wire is continuously molten by the high current and a large molten lump is formed at the end of wire. This lump is pushed up along the wire due to the strong arc force in T_P phase, but in the following T_B

Table 2 Chemical compositions of materials used.

		C	Si	Mn	P	S	Ti	Al	O	N
		0.23	–	–	–	0.01	–	–	0.001	0.0087
Wire	A	0.09	0.81	1.63	0.012	0.013	0.18	<0.01	0.012	0.0078
	B	0.07	0.70	1.54	0.018	0.014	0.17	<0.01	0.007	0.0048
	C	0.06	0.88	1.68	0.017	0.007	0.16	<0.01	0.004	0.0031
	D	0.09	0.91	1.38	0.015	0.009	0.003	<0.01	0.003	0.0035
	E	0.06	0.86	1.45	0.010	0.015	0.002	<0.01	0.004	0.0082

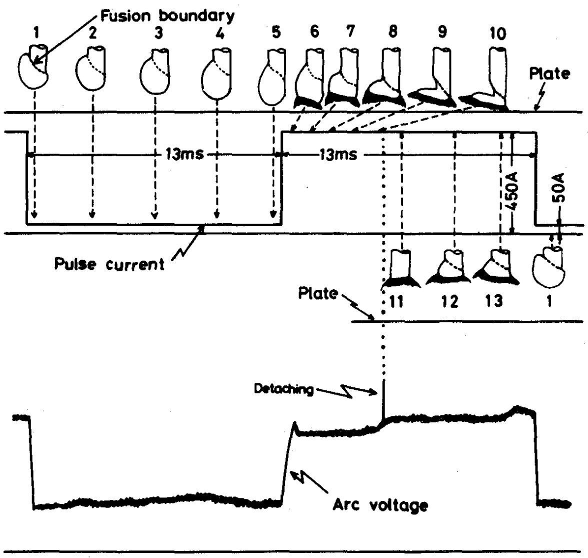

Fig. 3 Example of drop transfer behavior in pulsed CO_2 arc welding and current and voltage waveforms.

phase it begins to slide downward by the decrease in arc force and subsequently it is hung on the wire end. As restarting the high current, it rapidly detaches from the wire end and is transferred to the weld pool. The discussions on the proper conditions of successful one-drop-transfer operation are presented in the previous paper[1].

Applying pulsed current to the shortcircuiting transfer is also examined. The transfer phenomena and spattering in the case will be treated briefly in the later section and fully in the following paper.

There are many kinds of mechanisms for spattering in the CO_2 arc welding. These are divided into two catagories, one related to the mechanics in the transfer phenomena, and others. The latter is the one caused by chemical or metallurgical process in the weld pool like forming of carbon monoxide. In the pulsed CO_2 arc welding in open arc operation, the main process of spattering are classified into three types whose dynamic behavior are illustrated in **Fig. 4**.

Type 1 is the spattering concerned with a MHD instability (Kink Instability) induced in the neck of the wire just above the molten metal lump, due to the bending of the current path. The spattering occurs at the moment of detachment in the high current phase. The spattering of this type is most liable to arise and a diameter of spattered particle is very fine.

Type 2 is the one that a portion of drop is blown off due to arc-induced blow at soon after detaching.

Type 3 is the one ejected from the molten pool that may be caused by exhaustion of chemically reacted gas in the weld pool like CO_2 gas.

By applying pulsed current to CO_2 arc welding, spatter loss can be reduced to $\sim 1/5$ compared with usual CO_2 arc welding with constant potential power source, shown in **Fig. 5**. The reason is the current in the instant of detaching in pulsed CO_2 arc welding is lower than that in usual CO_2 arc welding[5].

4. Effect of Ti Content on Spattering

Effects of the difference in minor element in chemical compositions of the wire on the spattering were examined. Five wires tabulated in Table 2 were used. Spatter loss during welding and the number of times in occurrence of three types of spattering were measured.

Figure 6 shows the occurrence frequency of three types of spattering for five kinds of wire. Type 1 is dominant in the spattering for wires A, B and C, and Type 2 and Type 3 for wires D and E. In wires A, B and C, the spattering of Type 3 was suppressed to occur, compared to that in wires D and E. Since wires A, B and C are Ti-rich wires, it may mean the deoxidizing reaction by Ti in the weld pool is rather effective than the case in wires D and E.

Concerning to the Type 2 spattering, it is more in wires D and E, while the Type 1 spattering occurs more in wires A, B and C. The reason is not sufficiently clear. However,

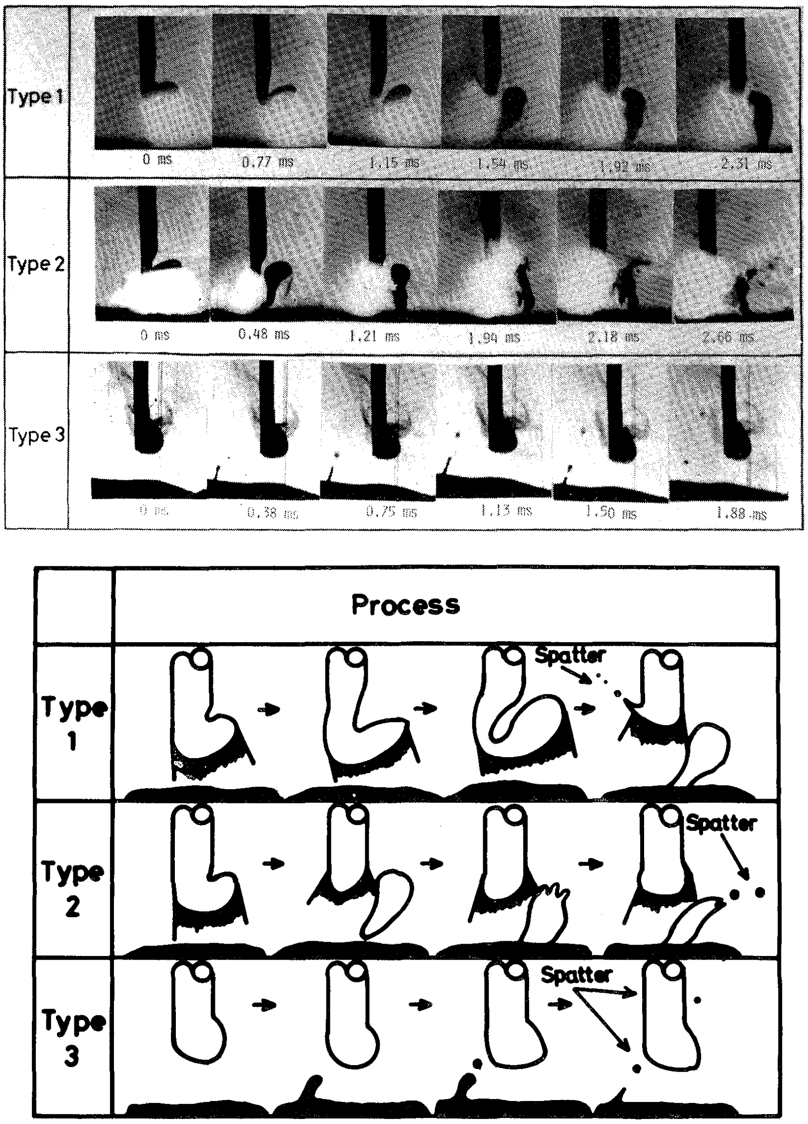

Fig. 4 Three types of spattering mainly occurred in pulsed CO_2 arc welding.

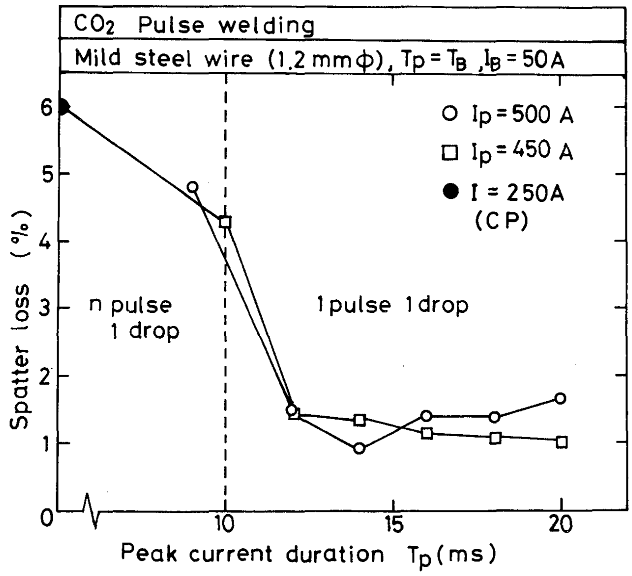

Fig. 5 Reduction of spatter by the use of pulsed CO_2 arc welding[5].

between this two groups of wire, a little difference in the behavior of detaching can be seen. The growth of constriction of the neck part of the wire seems to be rather faster in wires A, B and C than that in the wires D and E. The difference in Ti content in the molten metal has no decisive effect on the properties of surface tension, heat conduction and fluidity. So, it might be attributable to the difference in the temperature of molten lump which is caused by a little difference in electrical conductivity.

Figure 7 represents the influence of Ti content on spatter loss under the same condition of welding as that in Fig. 6. The sizes of spattered particle in the Types 2 and 3 are around 0.3–0.4 mm in diameter, while that in Type 1 is around 0.1 mm in diameter. The spatter losses in wires D and E are more than those in wires A, B and C. From these results, it is clear that the proper quantity of Ti in wire suppresses the spattering, particularly in Types 2 and 3.

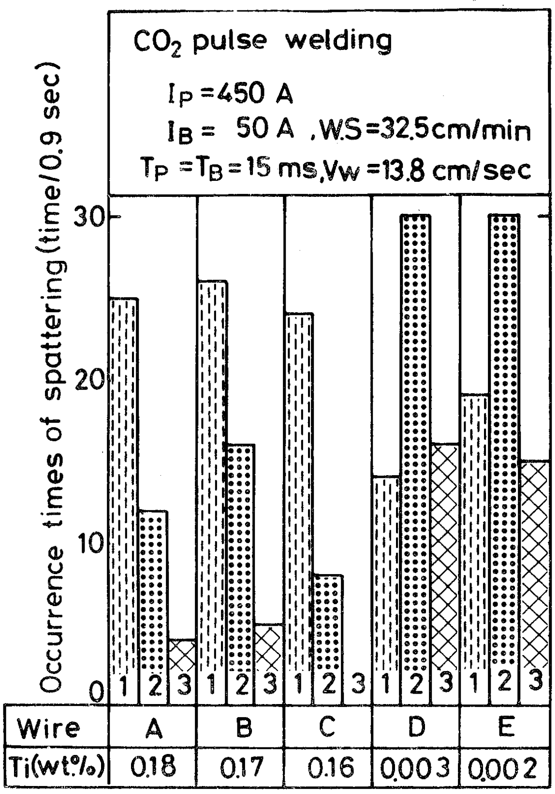

Fig. 6 Number of times in occurrence of three types of spattering for five kinds of wire.

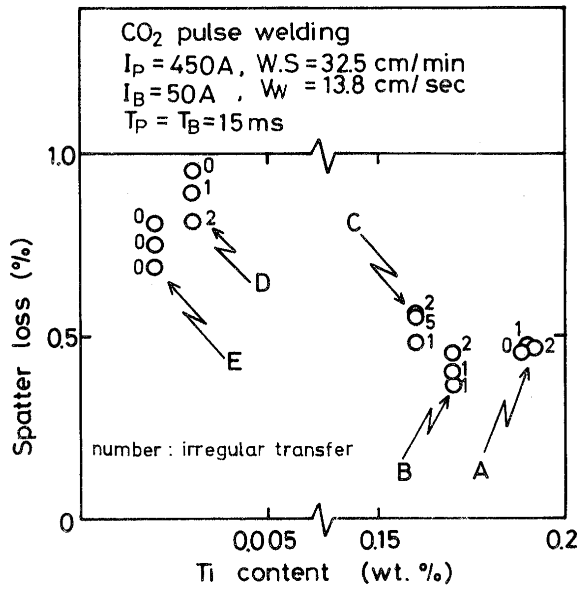

Fig. 7 Spatter loss measured for five kinds of wire.

5. Applying Three-stage Pulse Current to CO_2 Arc Welding

In the previous section, it is shown that a proper quantity of Ti in the wire is very useful to suppress the Type 3 spattering. Driving force of spattering of Types 1 and 2 comes from the electromagnetic energy which is directly related to the current value at the stage of detaching. Then, to reduce the current in the instant of detaching was attempted by the use of three-stage pulse current. The waveform of three-stage pulse current is already shown in Fig. 2.

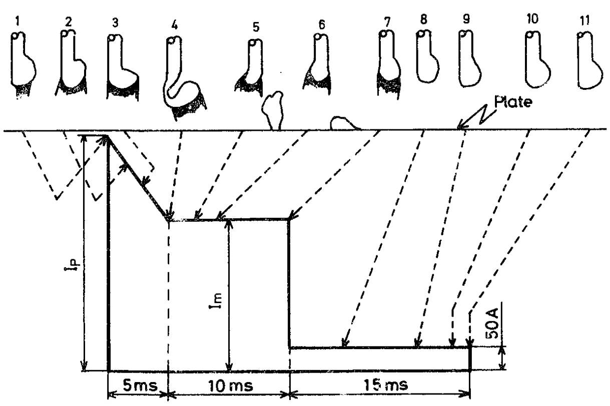

Fig. 8 Example of drop transfer behavior of three-stage-wave pulse current pulse welding.

A typical phenomenon of metal transfer is shown in **Fig. 8**. In the duration of peak current T_P, a strong pinch force is excited and the detaching occurs in the following middle stage in which the welding current is adjusted to rather lower value I_m.

Spatter loss in various case of I_m value in three-stage pulse current and it's comparison with that in rectangular-wave pulse current are shown in **Fig. 9**. By varying the I_m value, the spatter loss changes. There is a minimum in spatter loss around I_m = 350 A and it has little dependence on the I_P value. The numbers adjointed the plots represent the numbers of times in occurrence of irregularity in one-drop-transfer in a half of a minute. Increase in spatter loss in the lower range of current I_m is considered to be due to this irregularity, which is always associated with unstable arc and consequently give rise a spattering of large drop. The increase in the irregular transfer in the lower side of current I_m is due to the insufficient energy to complete the detaching.

Black dot represents the spatter loss in the case of rectangular-wave pulse current. The spatter loss in three-stage pulse welding which has the same current in averaged value as that in rectangular wave pulse welding, is shown by the dimmed mark pointed by the arrow corresponding to each I_P value. From comparison between the spatter in rectangular-wave pulse current and that in the three-stage pulse current, spatter loss can not be suppressed extremely even by the application of rather lower current in the instant of detaching.

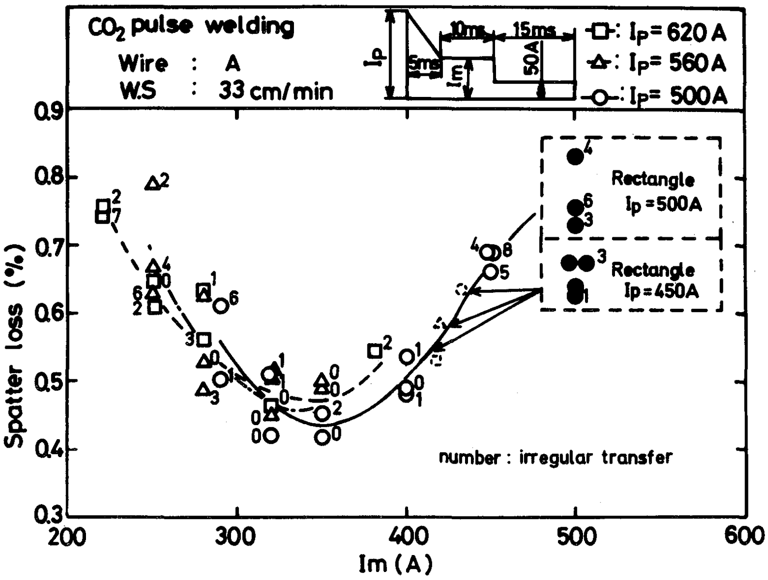

Fig. 9 Spatter loss in case of three-stage-wave pulse current CO_2 arc welding.

6. Applying Pulsed Current to Shortcircuiting Transfer in CO_2 Arc Welding

It is necessary to adjust precisely the parameters of pulsed current and feed rate of the wire, in order to obtain successful operation of shortcircuiting transfer in pulsed current CO_2 arc welding. Low current duration must be taken longer than the high current duration to bring the wire into contact with molten metal in the weld pool.

In this experiment the rectangular-wave pulse current was applied. Bridging between wire and metal in the pool during high current phase causes a violent irregularity in metal transfer. Therefore, the bridging in the low current duration is more required, also from the standpoint to reduce the spattering. In this case, the high current phase is used only to melt the wire end in an adequate quantity, because the molten metal lump should always be transferred to the weld pool during the following long T_B phase and there is little molten metal at the wire end in the instant of the restarting of high current. Therefore, the condition required for the time duration of T_P is that it must be sufficiently long to melt the wire end properly and not so long to give a rise to detach the drop.

Figure 10 is an example showing the shortcircuiting

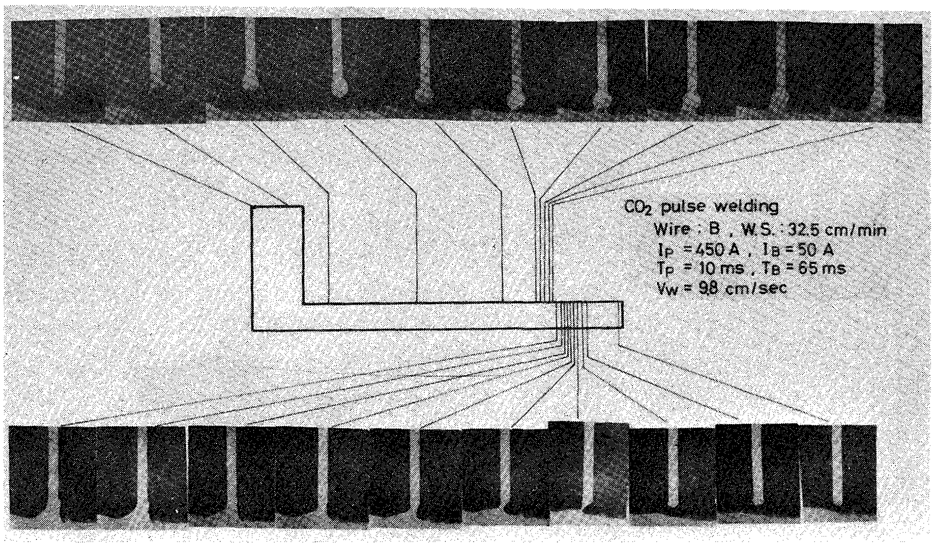

Fig. 10 Example of shortcircuiting transfer combined pulsed current in which spattering hardly occurrs.

transfer combined with the pulsed current. In the low current phase T_B the molten metal lump approaches to the weld pool due to the continuous feeding of wire, and shortcircuiting transfer is carried out due to the difference between the surface tension of molten lump and that of weld pool, the electromagnetic force and the gravity force. And just as the restarting of high current, the melting of wire end begins again.

Spattering hardly occurs except for the Type 3 spattering. Namely the shortcircuiting transfer combined with pulsed current can be a process of extinct spattering of Types 1 and 2.

However, there is a serious problem in this process, the instability of the process. The successful operation is realized only in the very narrow range of feed rate and pulse parameters. When the wire end fails to come in contact with the pool and it becomes open arc situation thoroughly in the low current phase, the process of grobular transfer mode mentioned in the previous sections begins and never fails to lead to the occurrence of spattering of Types 1 and 2 in the following high current phase. In order to extend the range of the condition of successful operation, the development of pulsive feed system of wire or the adaptive control of current is necessary.

7. Summary and Conclusion

In order to reduce the spattering in CO_2 arc welding, a pulsed current is applied.

It is shown that a simple rectangular-wave pulse current can give a successful operation in the open arc situation and the spatter loss is decreased to $\sim 1/5$ in comparison with that in the usual CO_2 arc welding.

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