Metal Transfer Characteristics in Self Shielded Flux Cored Arc Welding for Mild Steel and 50 kgf/mm^2 Class Tensile Steel (Report I)†

——Metal Transfer Mode and Feasibility of Welding——

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Abstract

Metal transfer and arc characteristics in self shielded flux cored arc welding for mild steel and 50 kgf/mm^2 class tensile steel were studied by using a high speed cine photographic technique. Basic type (included CaF_2) flux cored wire was used with electrode positive polarity. The following conclusions were obtained.

The metal transfer mode in self shielded flux cored arc welding was classified into three types, Bridging Transfer Mode, Free Flight Transfer Mode and Bridging Transfer without Arc Interruption Mode.

Bridging transfer mode operation resulted in good properties of the weld metal, while spattering occured and the spattered droplets were large. In the region of comparatively high arc voltage, the free flight transfer mode appeared, in which the size of spattered droplets were relatively small.

In bridging transfer without arc interruption mode which was realized in the region of higher current and higher feeding rate of wire, the spattering were extremely reduced.

KEY WORDS: (Self Shielded Arc Welding), (Flux Cored Wire), (Metal Transfer), (Self Shielded Flux Cored Wire), (Arc Welding.)

1. Introduction

Self shielded flux cored electrode wire, not requiring external gas shieling was introduced in the early 1960's. The process using the flux cored wire, which is known by abbreviated term, non-gas arc welding or self shielded arc welding, has the advantage of lower maintenance cost of system, poor sensitivity to wind draft, being able to weld with only simple torch and wire feeding system and so on. Therefore, this process has been applied to practical welding as an only semi-automatic welding process at outdoors. However, the weld has the defect of poor notch-toughness at low temperature.

In responding to this situation, continuing works have been done from the viewing point of improving notch-toughness and reducing nitrogen absorption. The electrode available today produce much better results than the previous one in mechanical properties of weld metal. Other improvements, however, which include reducing the weld fumes and spatter levels produced and improving the weld bead appearance characteristics are now continuing in research.

The arc behavior and metal tranfer phenomena in self shielded flux cored arc welding might be expected to be similar to those in gas metal arc welding with solid wire or in that with coated electrode. Metal transfer from comsumable solid electrodes across arc has been classified into three general modes of transfer. They are Spray transfer, Globular transfer and Bridging (Short circuitting) transfer. The metal transfer of most flux cored electrodes with externally shielding gas substantially resembles that with solid wire without the effect of chemical reaction within the molten droplet built up at wire end on the driving force of detachment and the effect of the shape of metal sheath cross section of wire on the formation and transfer of droplet[1, 2].

By contrast, the metal transfer and welding arc

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phenomena in the self shielded flux cored arc welding have not been enough studied. The purpose of this paper is to investigate the arc behavior and metal transfer in self shielded flux cored arc welding by using some typical wires which are composed by basic type flux and mild steel or 50 kgf/mm^2 class tensile steel for metal sheath.

With respect to the welder appeal, which is called "Feasibility of Welding", here, we will briefly discuss in association with welding condition. The factors included in "Feasibility of Welding" are the bead appearance characteristics, the covering of the slag formed on top of the weld bead and its removing after welding, spattering during welding, and the occurrence of porosities.

Effects of some key elements in flux, Aluminum, Barium, Sodium and so on, on the metal transfer characteristics and the feasibility are also studied. The report is submitted to the next number.

2. Welding Procedure

The conventional bead on plate arc welding is made by using a transistorized automatic welding machine with nearly constant potential characteristics (1.5V/100A). The welding speed is 250 mm/min and the welding torch is held downward in position by 30 mm above the plate. Applied polarity of welding is electrode positive (D.C.E.P.) one. Welding conditions are listed in **Table 1.**

Table 1 Welding conditions.

Welding Voltage	(Volt)	15,40
Wire Feeding Rate	(mm/sec)	43,62,92,130,150,177,242
Welding Speed	(mm/min)	250
Tip-Plate Distance	(mm)	30
Torch Angle	(degree)	90
Polarity		D.C. Electrode Positive

2. 1. Observation of arc phenomena

High speed cine-camera, HYCOM, is used to observe the welding phenomena. High speed motion pictures of 5000 frames/sec are taken by using a Xenon lamp as a backing light. The arrangement of the system is shown in **Fig. 1.**

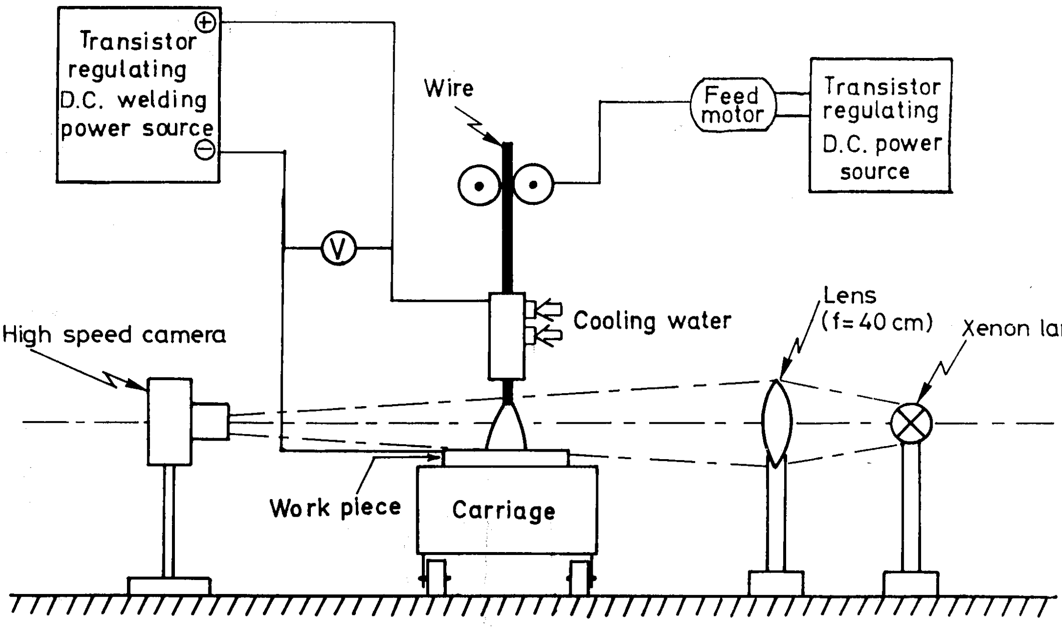

Fig. 1 Schematic illustration of experimental setup.

2.2 Materials

Chemical compositions of test plate, wire sheath and deposited metal are shown in **Table 2.** That of deposited metal was obtained by chemical analysis of some pieces of weld metals, which are deposited under most preferable welding condition. The test plate is 50 kgf/mm^2 class high tensile steel SM50A(JIS). Its dimension is 300 mm in length, 100 mm in width and 12 mm in thickness.

The wire sheath is made of mild steel thin sheet, and flux inside the sheath is of basic type included CaF_2 which is widely applied for self shielded flux cored arc welding. The chemical composition of flux is that of most fundamental ones, and listed in **Table 3**. The wire, which is called A-Wire throughout this report, have a diameter of 2.0 mm and its shape of cross section is single-folded cored one as shown in **Fig. 2**.

Table 2 Chemical compositions of materials used.

	C	Si	Mn	P	S
Test plate	<0.20	<0.55	<1.50	<0.040	<0.040
Wire sheath	0.05	<0.01	0.32	0.014	0.011
Deposited metal	0.06	0.10	1.13	0.012	0.004

Table 3 Chemical composition of flux.

Wire No.	Flux ratio (%)	Composition of core material (%)			
		CaF_2	Mn	Al-Mg	Others
A	20	45	5	25	25

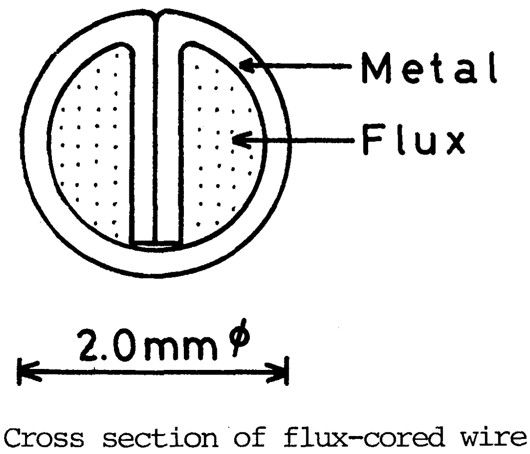

Fig. 2 Shape of cross section of single-folded flux cored wire.

3. Experimental Results and Discussions

3.1 Welding condition and classification of metal transfer mode

Figure 3 shows the operating conditions of welding, currents and out-put voltages in various feeding rates of the Wire-A. It can be seen the operating conditions are divided in four categories, I_a, I_b, II and III, from the view point of dominant mode of metal transfer during welding.

I_a and I_b represent the molten metal of wire is transfered to the plate in the modes of bridging transfer with and without arc interruption, respectively. In these modes the molten part of wire is transfered to the plate by intermittent bridging between them.

Generally the bridging causes the electrical short-circuitting and then usually the arc-off. In I_b, however, the arc does not disappear throughout the occurrence of bridging of molten part of wire.

The transfer mode in category II is so-called free flight one and electrical short-circuitting does not occur, due to the higher voltage of the arc. Under the condition in category III, the welding is impossible due to stabbing-in or sticking of the wire.

These three modes of metal transfer I_a, I_b and II were commonly observed in all wires with basic type flux.

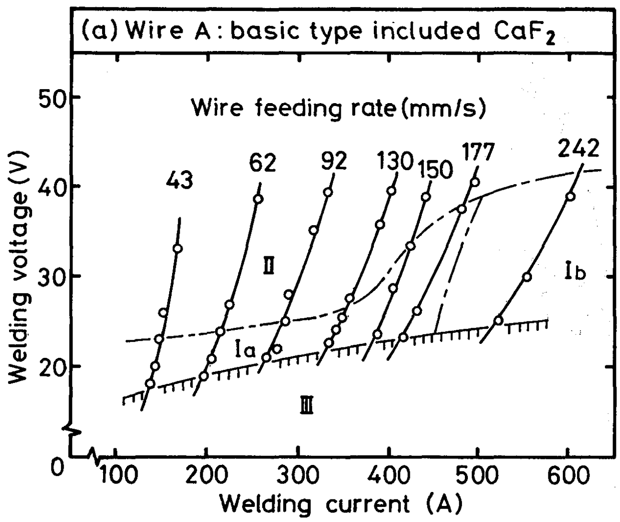

Fig. 3 Operating conditions of welding, currents and voltages in various feeding rates of Wire-A and classification of metal transfer mode.

3.2 Metal transfer

Metal transfer phenomena with the Wire-A were observed by using high speed cine films. The molten electrode metal forms the molten droplet together with the molten slag at the wire end, and is transfered to the molten pool in various mode above mentioned.

In I_a, the droplet became rather larger than that at higher current levels and did not detach from wire end unitl it bridges the wire end to the weld puddle. The situation can be seen in **Fig. 4 (a)**. In this mode there occurred electrical short-circuit so that steep spikes representing the short-circuit current could be appeared in current wave form shown in **Fig. 5 (a)**.

In II, Droplets at the electrode tip were not grown as large as that in I_a, and were transfered across the space to the weld pool. Driving force to detachment was seemed to be small explosion occurred inside the droplet resulted from intensive deoxdizing reaction, or free drop due to the gravity force. Then the mode was called the free flight transfer mode. In other words, the globular or the

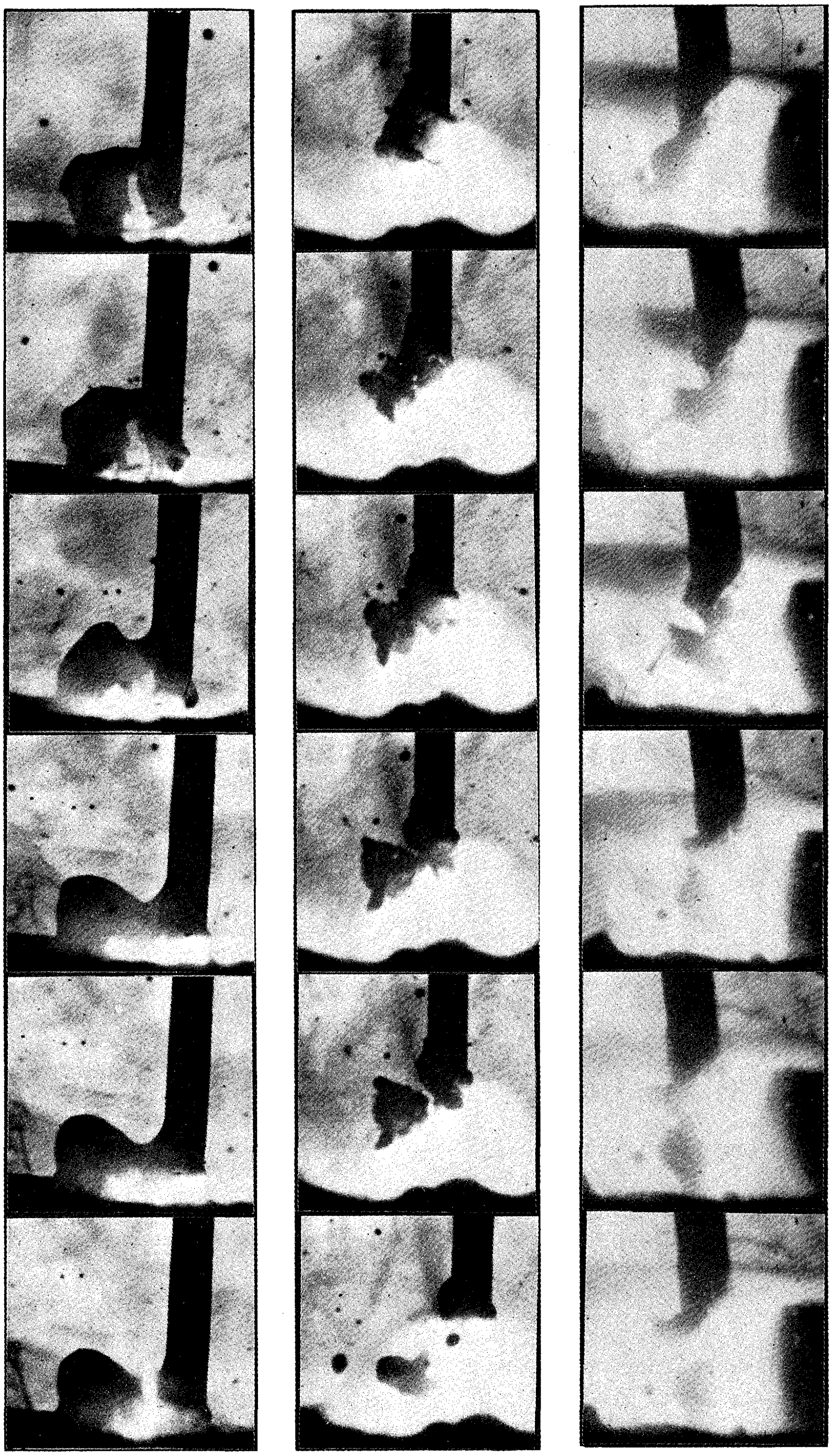

Fig. 4 Typical photographs of metal transfer in various modes.

explosive transfer mode is dominated.

The formation of molten droplet in this mode II is different from one in I_a mode. The molten droplet in I_a mode build up around periphery or outer metal sheath of the electrode. But in the mode II, the build up of molten droplet is not so clear. And in I_a the droplets have rather smooth and round contour in shape, and large volumes compared to those in mode II, in spite of the same melting rate of the wire. This results may suggest that the intense slag-metal reaction resulting in the producing of gas occurred inside the droplet in mode I_a.

In I_b, the wire tip was melted asymmetrically and droplets were transfered in the bridging transfer mode while it were relatively small in size (Fig. 4 (c)). The electrical short-circuitting occurred due to the bridging of the molten metal but the arc does not disappear. Welding arc was mostly burried in the molten pool and attack the front wall of the well space produced in it. Droplets were bridged towards rear wall of the space and transfered to the molten pool.

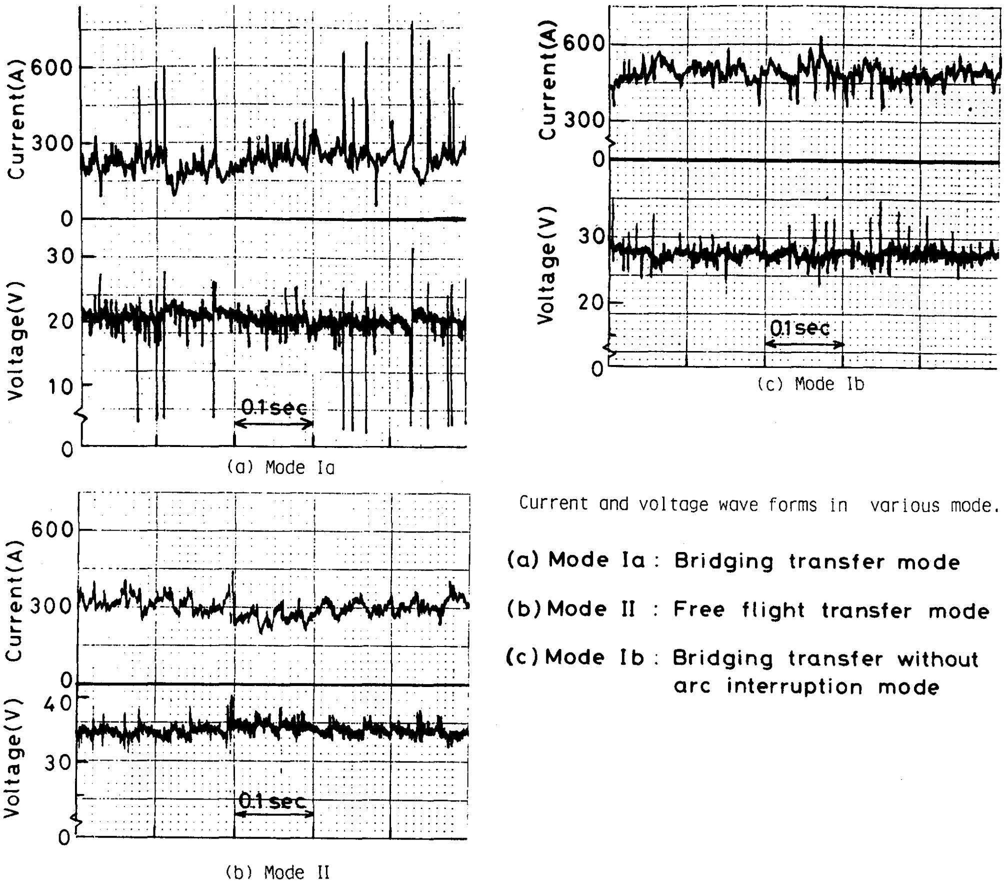

Fig. 5 Current and voltage wave-forms in various metal transfer modes.

3.3 Spattering

In I_a, the spattering was much increased in quantity and the size of spattered droplets were as large as the same order of wire diameter. On the other hand, in II the quantity of spattering decreased and the size of spattered droplets were relatively small. In the range in I_b, the spattering were extremely reduced.

It is considered that the spattering occurs mainly in association with short-circuitting. Just after the molten droplet at the wire end enters the weld puddle and bridges the arc gap, spattering or splash-away of molten material does occur due to the melt-off action of electrical short-circuit. The occurrence of the phenomena decreases with the smaller droplet size. In I_a mode, the size of droplet was larger than that in II, and the short-circuitting in I_a was also more frequent as shown in Fig. 5. This is the reason why many spattering occurred in I_a than in II.

The spattering were extremely reduced in I_b. In this mode, welding arc is the burried arc. It has incomplete short-circuit character in electrical sense even when the molten droplets are transfered by the bridging. Therefore, if the explosion of molten droplet does occur, the spattered particles are absorbed in the wall surrounding the burried arc. And, explosive fusion of bridging part of the droplet tends not to occur by the coexistence of arc current.

3.4 Feasibility of welding

The feasibility of welding means the evaluation of the wire with respect to bead appearance, the ease of slag removal, the completeness of slag covering during welding and the prevention of porosity.

Figure 6 represents the improper zone of welding condition concerning to the above factors. Satisfactory usability could be obtain under the condition included in I_a mode region for the Wire-A. In mode II, which is the higher voltage region, the used wire could not provide the preferable results for all of factors of feasibility.

Particulary under the condition of I_b mode, porosities as wormholes were frequently found. It might be due to the decrease in shielding effect resulted from the higher levels of arc current. Arc force, which is associated with the intensity of arc current, could push away the molten slag covering the rear area of molten pool.

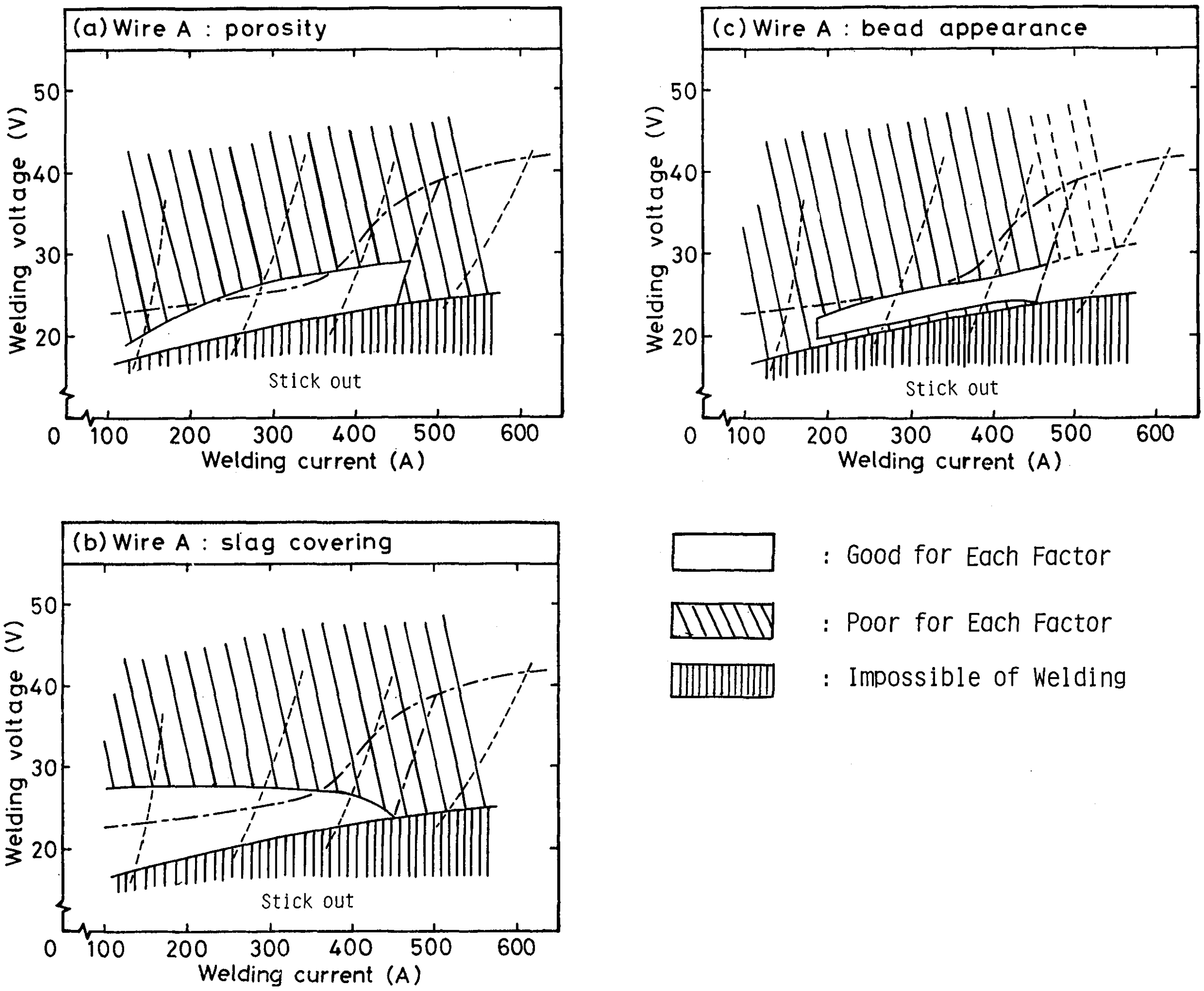

Fig. 6 Improper zone of welding with respect to bead appearance, slag covering and removal, and prevention of porosity.

4. Conclusions

The following conclusions were obtained as the results of the investigation on metal transfer phenomena in self shielded arc welding with flux cored wire with basic type flux.

(1) The metal transfer mode in self shielded arc welding for flux cored wire with basic type flux was classified into three types, Bridging transfer, Free flight transfer

and Bridging transfer without arc interruption modes. They were related to the welding parameters, current, voltage and wire feeding rate.

(2) In bridging transfer mode appeared under the lower voltage condition, droplets became relatively large and were not transfered without bridging. In the free flight transfer mode appeared under the higher voltage condition, droplets did not become as large as those in the bridging transfer mode, and detached more frequently.

(3) In bridging transfer mode, the spattered droplets were as large as the same order of the wire diameter, and in the free flight transfer mode the size of the spattered droplets became relatively small. In the bridging transfer without arc interruption mode, the spattering were extremely reduced.

(4) The proper welding from the viewing point of the bead appearance, the covering of slag during welding, the removing of slag after welding and preventing of porosity, could be found in the operating condition in the bridging transfer mode region.

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