Arc Characteristics and Metal Transfer with Flux-Cored Electrode in CO_2 Shielding (Report I)†
– Effect of Geometrical Shape in Wire Cross-section on Metal Transfer in Stainless Steel Wire –

Fukuhisa MATSUDA*, Masao USHIO, Tatsuo TSUJI*** and Toshihiko MIZUTA******

Abstract

Metal transfer and arc characteristics of CO_2 welding with flux-cored wires which had various geometrical shapes were studied by using a high speed cine photographic technique and electrical measurements. Tow types of flux-cored wire in cross-sectional shape were used, that were wires with simple hollow-shaped metal sheath and those with fold-shaped metal sheath. The following conclusions were obtained.

The difference in the averaged melting rate in the free flight transfer mode[4] among these wires was mainly depended on the difference in electrical resistance of the wires.

In the case of hollow-shaped wires, the molten metal collected at the side of the wire tip and formed the large globule which was separated from the molten flux. The detaching of the molten metal was mainly due to the explosion at the wire tip. Moreover the molten flux was periodically dropped in the free flight transfer mode.

In the case of the fold-shaped wires, the molten metal didn't form a globule at the wire tip and detached mainly in accompanying with the dropping of the slag.

KEY WORDS: (Flux-cord Wire) (CO_2 Welding) (Arc Welding) (Metal Transfer) (Stainless Steel) (Arc Characteristics)

1. Introduction

The concept of flux-cored wires was invented in 1927, but the wire has not been practically used for many years mainly because of the economical disadvantages. Lately, in relation to the advance in automatic welding process, the advantages of the flux-cored wire has become of general interest. The wide range of operating conditions applicable to practical welding, the good stability of quality control of weld and so on, increase the use of the flux-cored wire especially in non gas shielding welding. In responding to this situation, many works [1,2,3] have been carried out from the view point of slag-metal chemical reaction. However, little has been known about the metal transfer phenomena with flux-cored wire in CO_2 shielding.

The purpose of this paper is to investigate the metal transfer and arc phenomena in CO_2 arc welding with flux-cored wires of austenitic stainless steel which have various geometrical shapes in wire cross-section.

First the authors have measured the relation between the melting rate of flux-cored wire and the electrical characteristics of the welding arc for various wires. Secondly, by using high speed cine films, the chracteristic features of metal transfer of CO_2 welding with those wires have been observed and discussed.

2. Experimental Procedures

Chemical compositions of test plate, wire sheath and

Table 1 Chemical compositions of the materials used in this experiment.

	C	Si	Mn	P	S	Cr	Ni
Test plate	<0.20	<0.35	0.60 ~ 1.20	<0.040	<0.040	18.0	9.0
Wire sheath	<0.08	<0.90	<2.50	<0.040	<0.040	18.0 ~ 21.0	9.0 ~ 11.0
Deposited metal	<0.15	<0.90	<2.50	<0.040	<0.040	22.0 ~ 25.0	12.0 ~ 14.0

† Received on September 21, 1979
* Professor
** Associate Professor
*** Technical Director, Sumikin Welding Electrode Co., Ltd.
**** Research Engineer, Sumikin Welding Electrode Co., Ltd.

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

deposited metals are shown in **Table 1**. The test plate is mild steel SM-41B (JIS). Its size is 200 mm in length, 150 mm in width and 10 mm in thickness. The wire sheath is made of stainless thin sheet, and flux inside the sheath is usual one which is used for CO_2 welding. The wire diameter of all wires except Chemetron-7000 (1.6 mm) which is used for the comparison with them is 2.0 mm. In order to observe the differences among the metal transfer of the flux-cored wires with various shapes in cross-section, five types of wire are produced by using the same compositions of flux and stainless steel. Their cross-sections are shown in **Table 2**. Area of the metal

Table 2 Dimensions and shapes of flux-cored wires used.

Type of wire	Mark	Cross section of wire	Dia. (mm)	Thickness of metal (mm)	Area of metal (mm²)	Area of metal Ratio(%)	Weight ratio (Wt%) Metal	Weight ratio (Wt%) Flux
Fold-shaped sheath wire	A		2.0	0.25	1.92	61.1	76.9	23.1
	B		2.0	0.24	1.84	58.6	77.4	22.6
	C		2.0	0.20	1.84	58.6	77.5	22.5
Hollow shaped sheath wire	D		2.0	0.33	2.05	63.3	90.1	9.9
	E		2.0	0.24	1.90	60.5	74.2	25.8
Chemetron 7000			1.6	0.55	1.48	73.4	—	—

sheath is measured from photogragh of wire cross-section. Weights of metal sheath and flux are separately measured after unfolding the wire of 100 mm in the length and the ratio these weight to total one is devived. Conventional bead-on-plate arc welding is made by using a transistorized automatic welding machine with a constant potential characteristic. The welding speed is 600 mm/min and the flow rate of CO_2 shielding gas is 20 liters/min. The welding torch is held downward in position by 20 mm above the plate. Welding conditions are shown in **Table 3**.

Table 3 Operating conditions of welding.

Arc Volage	(Volt)	20, 36,
Wire Feeding Rate	(mm/sec)	34, 57, 88, 125, 168,
Welding Speed	(mm/min)	600
Gas Flow Rate	(liter/min)	20
Wire Extension	(mm)	20
Torch Angle	(degree)	90
Polarity		D.C. Wire (+)

High speed cine-camera, HYCOM, is used to observe the welding phenomena. High speed motion pictures of 4500 to 8000 flames/sec are taken by using a carbon arc or a He-Ne laser as a backing light. There are arranged as shown in Fig. 1.

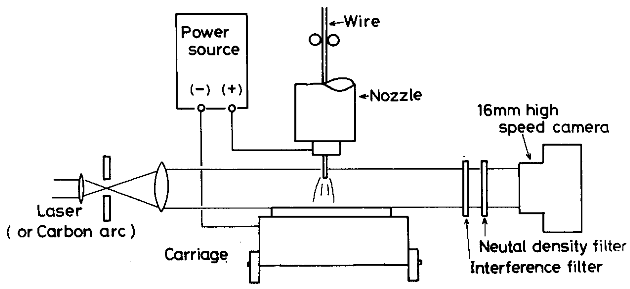


Fig. 1 Experimental set up.

3. Experimental Results and Discussions

3.1 Melting Rates

Figures 2 (a) to (e) show the current and voltage characteristics in various feeding rates of flux-cored wires. The feeding rate was equal to the averaged melting rate at steady state of consumable electrode arc. In figures 2 (a) to (e), range I, II and III indicated free flight transfer mode[4], bridge transfer mode and globule transfer mode. From these data of melting rates at constant arc voltage of 30 V are replotted in relation to the arc current for

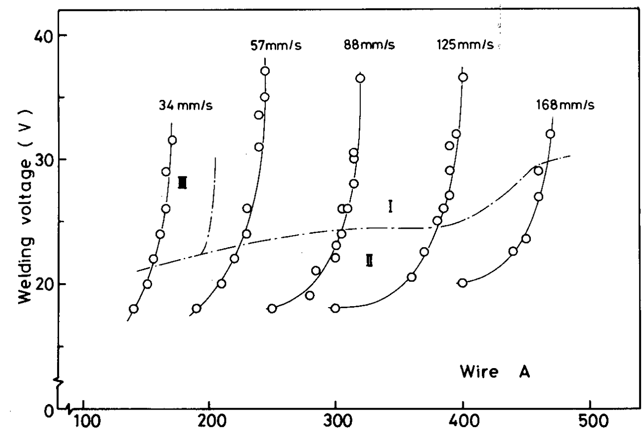


Fig. 2 (a)

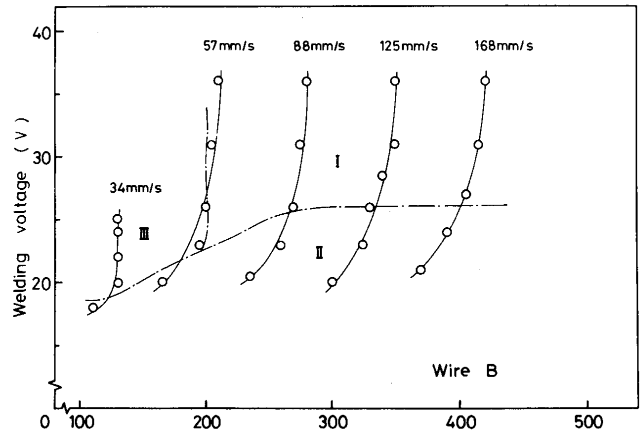


Fig. 2 (b)

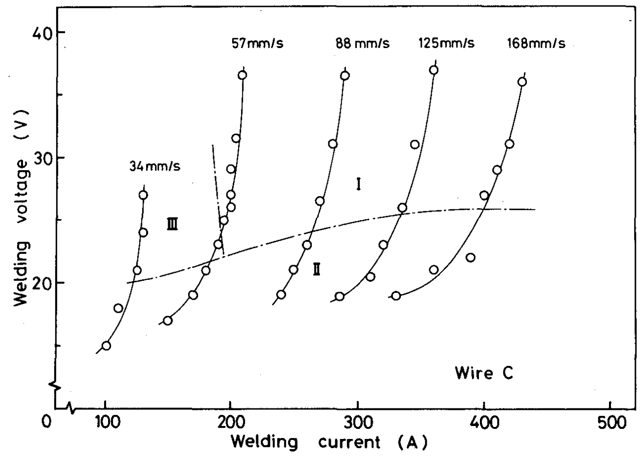


Fig. 2-(c)

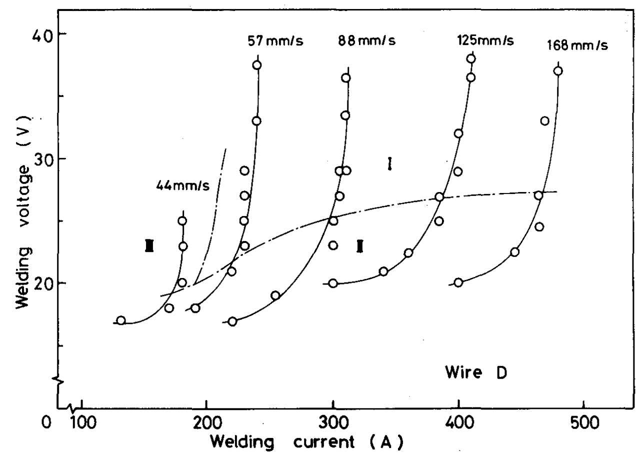


Fig. 2 (d)

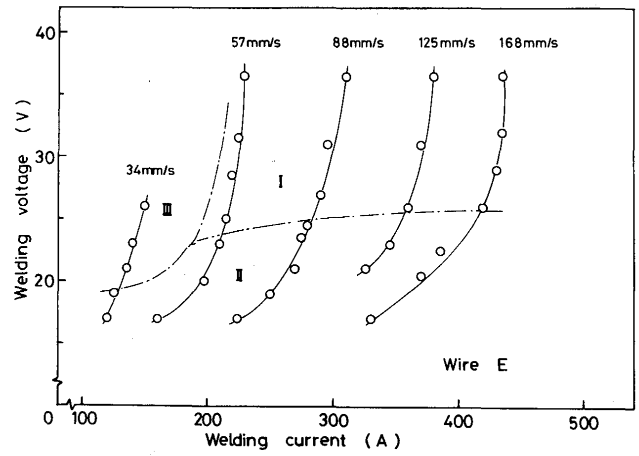


Fig. 2 (e)

Fig. 2 Current and voltage characteristics of CO_2 welding arc with various types of flux-cored wires in various feeding rates, and classification of metal transfer mode related to arc condition; (I) Free flight transfer mode, (II) Bridging transfer mode, (III) Globuler transfer mode.
(a) Wire A (b) Wire B (c) Wire C (d) Wire D (e) Wire E

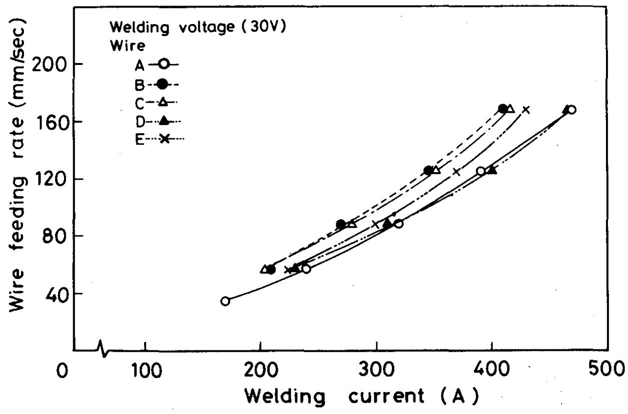


Fig. 3 A typical melting rates at constant arc potential of 30 V. These are derived from the date shown in Fig. 2-(a) to (e).

various wires, which are shown in **Fig. 3**.

It could be seen that there were differences in the arc currents among various wires at the same melting rate. The difference of about 10 % in arc current exists between the wire A or D and wire B or C, whose wires give maximum difference in arc current at the same melting rate.

Roughly speaking, the major part of the power required to raise the temperature of the solid metal to the melting point, is supplied by Joule heating of the extension in consumable metal arc welding. With respect to the solid steel wire, it is proved in CO_2 welding and plasma MIG welding.[5,6] The metal parts of the cored-wires used in this experiment consists of the same material and chemical compositions of the fluxes are also the same among those wires. If the chemical reaction between wire shell and flux at the wire tip where the metal drop is formed has no effect on the averaged melting rate of the wire, the differences in the melting efficiency of various wires at the same current are attributable to the differences of efficiency in Joule heating of wires.

In **Table 4.**, the electrical resistances of the various

Table 4 Electrical resistivity of the wires derived from the measured resistances of wires of 50 cm in length.

Wire	Electrical Resistance (Ω mm)
A	3.7×10^{-4}
B	4.0×10^{-4}
C	4.1×10^{-4}
D	3.3×10^{-4}
E	3.8×10^{-4}

wires measured by the Impedance-Bridge Meter at the room temperature are displayed. Although these values are not the ones at the high temperature, the differences in the electrical resistance of these wires are held in the similar manner in the high temperature state because of the same chemical compositions of wire metals. The maximum value of differences in the resistance of the various wires was 20% of the lowest value of the resistance. These differences in the resistance of the wire could be the main reason of diffences in the arc current at the same melting rate, as well as the case of solid steel wire welding.

3.2 Metal Transfer

Metal transfer phenomena of CO_2 welding with various flux-cored wire were observed by using high speed cine-films. Five types of flux-cored wires above mentioned, the Chemetron-7000 and a flux-less hollow type wires were used.

In the case of the hollow type wire which is metal tube without flux and 1.6 and 0.5 mm in outer and inner diameter, respectvily, the metal transfer phenomena was well similar to that with solid wire. A large globule was formed at the wire tip, which was shown in **photo. 1**. The globular molten metal was transfered in the bridging transfer mode, accompanying with the electrical short-circuitting and the violent spattering of the molten metal. The molten metal transfer with flux cored wire was quite different from that with flux-less hollow type wire which was shown **photo. 2**. At the same condition of the welding current and voltage, the bridging transfer could not be seen and it changed into the free flight tranfer.

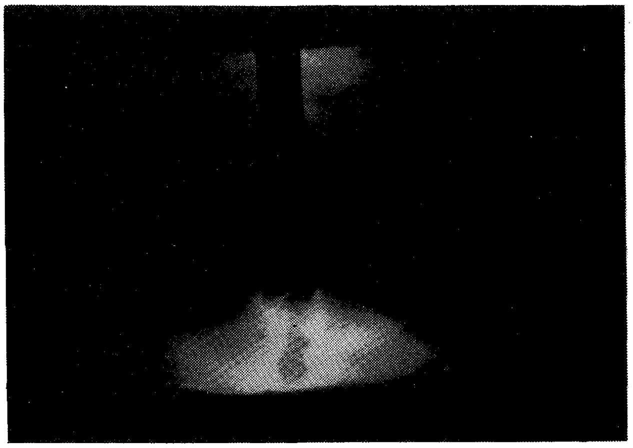


Photo. 1 (a) A typical photograph representing the formation of the globule at a side of the wire end in the case of hollow type wires.
(b) Bridging of slag.

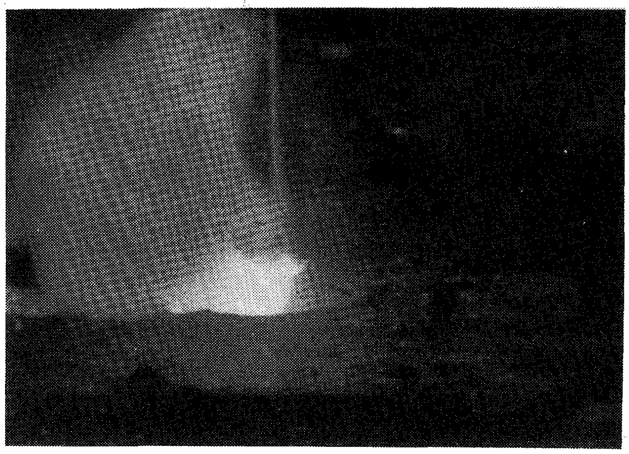


Photo 2 A typical photogragh representing the forming of a large globule at a side of the wire end in the case of flux-less wire.

In Fig. 2-(a) to (e), the classifications of metal transfer mode with these wires are shown with the number mark I to III.

The region I was ranging from 200 to 500 A in arc current and higher out-put voltage. With the operating condition in this region, the molten metal were transfered in the free flight mode and the current wave forms were shown in **Fig. 4**. In this region, it was apparently ovserved

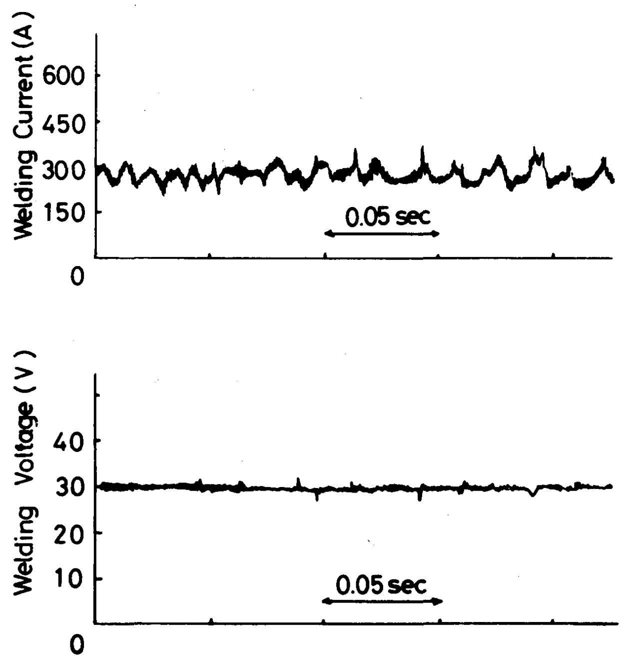


Fig. 4 Current wave form in the free flight transfer mode.

that the molten metal and flux transfer in various manner corresponding to the geometrical difference in the shape of metal part of wire.

The region II was ranging from about 200 to 500 A in arc current and lower out-put voltage, in which the arc length is very short and the electrical short-circuitting took place frequently. The molten metal was transfered mainly in the bridging transfer mode.

The region III was below 200 A in arc current, the molten metal was transfered in the free flight mode, but the size of droplet is comparably large globule. As an example, it was routhly 4/5 to 1 of wire diameter in case of Chemetron-7000 wire. Occasionally arc roots at the wire tip localized on the skirt of the metal sheath.

In the case of the wire D, E and Chemetron-7000 whose geometrical shape of the metal part were hollow-shaped sheath the molten metal collects to the one side of the wire tip and becomes to a large globlule of about same size as wire diameter, which is shown in **photo. 3**. Some-

Photo. 3 Metal transfer in case of hollow-shaped sheath wire.

times the globule droped collecting in the side of the wire were separately from fusion flux as shown in **Photo. 4**.

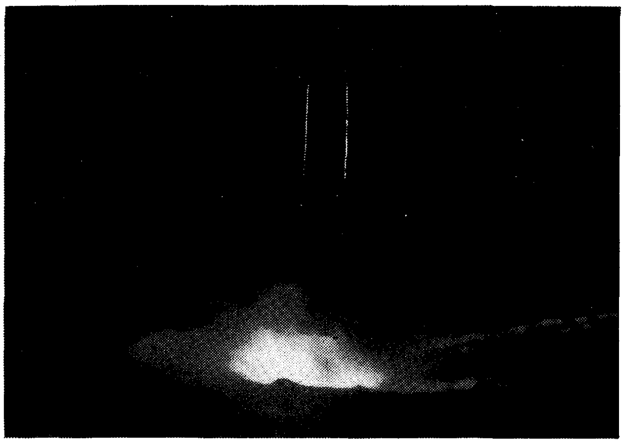
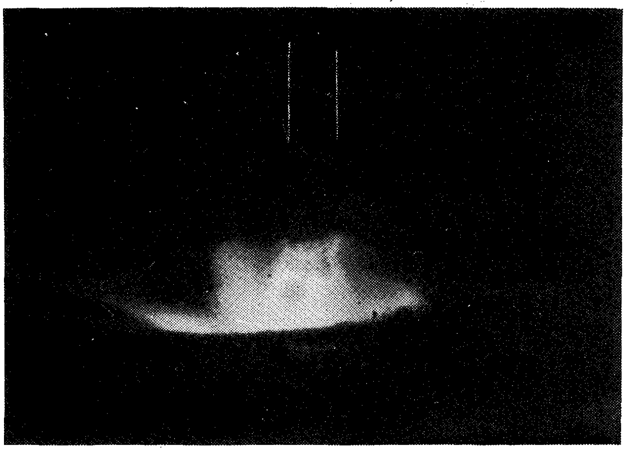


Photo. 4 Metal transfer in case of hollow-shaped sheath wire.

Moreover the globule droped suddenly into the weld pool, but frequently it is assosiated with the occurrence of the explosion at the wire tip.

On the other hand, such a large globule as appeared in the case of wire D was not formed at the wire tip in cases of fold-shaped sheath wire A, B, and C. With A, B, and C, the driplet was comparably smaller than the wire diameter. But the shape of droplet was not spherical, and metal and flux together detach from the wire tip as if the wall moulds as an example in **Photo. 5**. Detouching of the



Phot. 5 Metal transfer in case of fold-shaped sheath wire.

droplet was seemed to the drop of the slag rather than the explosion at the wire tip.

In general, the flux transfers to the molten pool along the wire axis and caused the bridging of the slag to the pool especially in shorter arc condition. Moreover, the bridging of the slag between the electrode and the molten pool occured easily in cases of wire D and Chemetron-7000. But it gave no effect on electrical condition of the arc.

Droplets transfering in the welding arc were roughly classified into three types of particles; the metal, the flux and the mixed one of them. In order to collect the droplets, the arc is burnt between the flux-cored electrode and the carbon electrode with CO_2 shielding. The experimental set up was illustrated in **Fig. 5**. In the case of

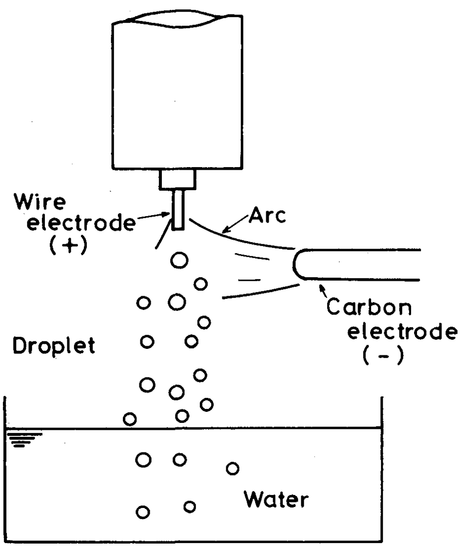


Fig. 5 Experimental set up for collecting the transfered droplet.

the wire D, E or Chemetron-7000, it could be seen many large particles whose size was almost the same as the wire diameter. In the case of the other wires A, B and C, the size of collected particles was smaller than the wire diameter and the scattering in its size was also small. And almost the metal particles were covered with slag.

4. Conclusions

The following conclusions were obtained as the results of the investigation on the metal transfer phenomena in CO_2 arc welding with flux-cored wires;

(1) The difference in the averaged melting rates of flux-cored wires with various geometrical shapes in wire cross-section are dominantly depended on the difference in the electrical resistance of the electrode wire.

(2) At the presence of flux, the operation range of the free flight transfer is extended more widely.

(3) The occurrence of detaching of the droplet is due to explosion at the wire tip, or dropping accompanied with that of flux, and the droplets consists of the metal, the flux and mainly the mixed one of them.

(4) The behavior of metal transfer in the free flight mode differs between the wire with hollow-shaped metal sheath and the one with fold-shaped metal sheath across the cored-flux. In the case of the wire with the hollow sheath avarge droplet is formed at the side of the wire tip and therefore many large droplets whose size is comparable to the wire diameter appear. The droplets in the cases of the fold-shaped sheath wire are smaller than the wire diameter and they are almost the metal particles covered with slag.

Acknowledgement

The authors would like to thank Mr. Kenji Toumoto for his useful assistance, and Mr. Tadashi Itoh for producing the flux-cored wires in this experiment.

References

1) P. Stular: "Metal Transfer with Cored Electrode in Various Shielding Atomosphers", Physics of the Welding Arc Symposium, London, 1962.
2) D.C. Smith: "Flux Cored Electrode –Their composition and use", Welding Journal, Vol. 7 (1970), p535
3) O. Morigaki, et.al.: "Some Improvement in Self-shieled Flux cored Electrode for Arc Welding", Welding Journal, Vol.-8 (1976), p241-s.
4) Anon.: "Classification of metal transfer", IIW. Doc, XII-636-76
5) M.B.C. Quigley & J.M. Webster: "Metal Transfer in Arc Welding", International Conference on Welding Reserch Related to Power Plant, 1972.
6) J.H. Waszink, et.al: "Measurements and calculations of the resistance of wire extension in arc welding", Physics of the Welding Arc Symposium, London, 1979.
7) E. Helmøy: "Wire melting rate, droplet temperature, and effective anode melting potential", Physics of the Welding Arc Symposium, London, 1979.