Arc Characteristics and Metal Transfer for Flux-Cored Electrode in GMA Welding (Report II)†

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Abstract

Arc characteristics and metal transfer with flux-cored wires which have various content ratios of iron powder in flux were studied.

The increase in adding ratio of iron powder into flux in flux-cored wires diminished their melting rate of wire and the size of transfering droplets. Moreover the distribution of size of droplets was measured. The size of droplets transfered with flux-cored electrode in free-flight transfer mode was similar to that with solid wire in spray transfer mode.

The effect of the compositional ratio of CO_2-Ar shielding gas on the size of droplets transfered was a little with flux-cored electrode.

KEY WORDS: (Flux-Cored Wire) (Metal Transfer) (Arc Characteristics) (Shielding Gas) (Droplet Diameter)

1. Introduction

Recently, it has been considered that the iron powder is added to flux in flux-cored electrode in order to increase deposition rate in welding and improve arc stability.

However, little have been known about its effect within the authors' knowledge. The purpose of this study is to investigate the influence of addition on iron powder into flux on arc characteristics and metal transfer mode from fundamental standpoint. In this study, the authors have investigated about the wire melting rate, the arc phenomena, the distribution of droplet diameter transfered and the chemical composition and porosity in weld metal in changing the additional ratio of iron powder in flux of flux-cored electrodes.

Moreover, the influences of composited ratio of CO_2-Ar shielding gas have been investigated.

2. Welding Procedure

Welding power source, wire feeding system and welding conditions used in this experiment are same as that in the previous paper [1]. For investigation of the effect of composition of flux, various flux-cored electrodes were made by forming the mild steel strip (C: <0.05, Si: <0.01, Mn: 0.31, P,S: 0.015%) into O-shape in 1.6 mm diameter, as is shown in **Fig. 1**, in which flux is packed with and

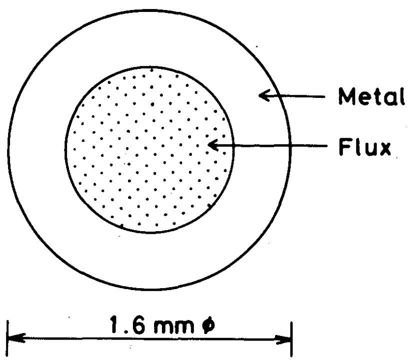

Fig. 1 Crosssection of flux-cored wire.

Table 1 Composition of core material

Mark	Usual flux (vol %)	Iron powder (vol %)
M-1*	0	0
M-2	100	0
M-3	80	20
M-4	60	40
M-5	40	60
M-6	20	80
M-7	0	100
Solid wire (JIS YCW-2) 1.2, 1.6 mm ϕ		

* Ratio metal to flux in area of crosssection in wire M-1, 1.93/0.08 = 24.1, in wire M-2 through M-7, 1.35/0.66 = 2.05.

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without iron powder as core material. The composition of core material is shown in **Table 1.** Wire M-1 is a cylindrical tube without core material. The composition of usual flux is titania type.

Solid wire (JIS YCW-2) was used for comparing with flux-cored electrode in arc and metal transfer characteristics.

In the experiment of the measurement in the distribution of the size of droplet, another flux-cored wires A through E (wire material of AISI 304 stainless steel) which was examined in the previous paper, were also compared.

In case of mixed shielding gas, the gas mixer was used to be the fixed ratio of composition of CO_2 and Ar gases.

In order to determine the distribution of the size of droplet transfered, the authors have used the procedure which was carried out by Ishizaki and Kohbe[2]), that is, the droplets which were emitted during the arc ignited between the flux-cored electrode and carbon electrode which was put in right angle for that were collected in water. The droplets were dried up, divided metal and slag by the mechanical polish, classified in its outer diameter by various sieves and weighted in each droplet size.

3. Experimental Results and Discussion

3.1 Melting and metal transfer characteristics with various compositions of core material

3.1.1 Relation between the melting rate and the composition of core material

The data of melting rates at constant arc voltage of 30 volt are plotted in relation to arc current for various wires in Table 1, which are shown in **Fig. 2**. The melting rate increased with welding current, but it decreased with increasing of the content of iron powder in core material, and became similar to the melting rate of the solid wire (1.6 mm ϕ).

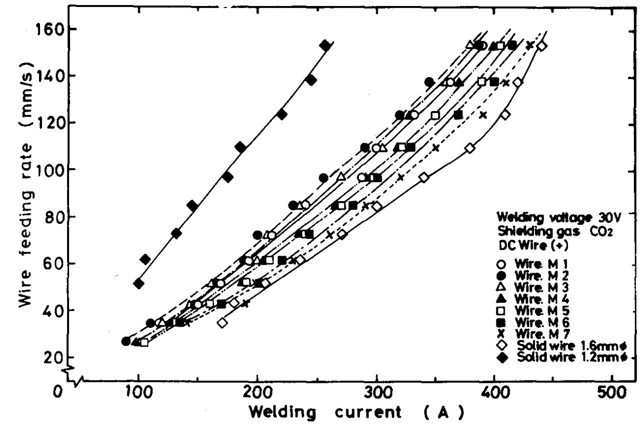


Fig. 2 A typical melting rates at constant arc potential of 30 V (wire extension; 20 mm).

The electric resistance of the various wires was measured by Impedance-Bridge Meter at room temperature, and there are tabulated in **Table 2.** The value of the electric resistance is decreased with increasing of the content of iron powder in core, as is evident from Table 2. But in the solid wire, the resistance is so high, because it is composed of more alloying elements in it than in the metal sheath of flux-cored electrode. The chemical composition of the solid wire is 0.80% in Si, 1.50% in Mn and 0.07% in C for example.

Tabel 2 Electric resistance of wires

Wire	Resistance ($\mu\,\Omega$ mm)
M-1	14.2
M-2	14.0
M-3	13.1
M-4	13.0
M-5	12.4
M-6	12.2
M-7	11.9
Solid 1.6 mmϕ	28.8
Solid 1.2 mmϕ	28.3

3.1.2 Relation between the metal transfer and the composition of core material

Figures 3 (a) and (b) show the current and voltage characteristics in various feeding rates of solid wire and flux-cored electrodes, respectively. The three ranges in metal transfer mode are shown in these figures. The types of metal transfer which were observed were similar to those of flux-cored electrodes which were made of stainless steel used in the previous report.

At 300 amperes in welding current and 30 volts in arc voltage which is a typical example of the welding condition, the electrode tips of solid, M-1 and M-3 wires are shown in **Photo. 1 (a), (b) and (c).** At the electrode tips of solid and M-1 wires a large globule was formed, but in M-3 wire it can be seen that core flux wasn't melted down and remained in the center of the arc during welding.

In this condition, current and voltage during welding are shown in **Fig. 4 (a), (b) and (c).** From these data in solid and M-1 wires, it could be seen that the short-circuiting took place, when the molten metal detached. Therefore, the globule which was formed at their electrode tips came in contact with the molten weld metal before it detached from the wire tip. On the other hand, as a short-circuiting was scarcely seen in M-3 wire, a globule may be detached without contact to the molten weld metal.

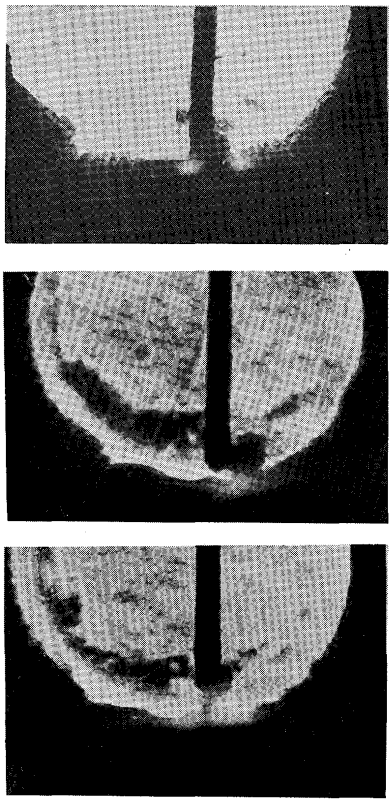


Photo 1 Typical example of electrode tips of (a) solid, (b) M-1 and (c) M-3 wires with CO_2 shielding at 300 A-30 V.

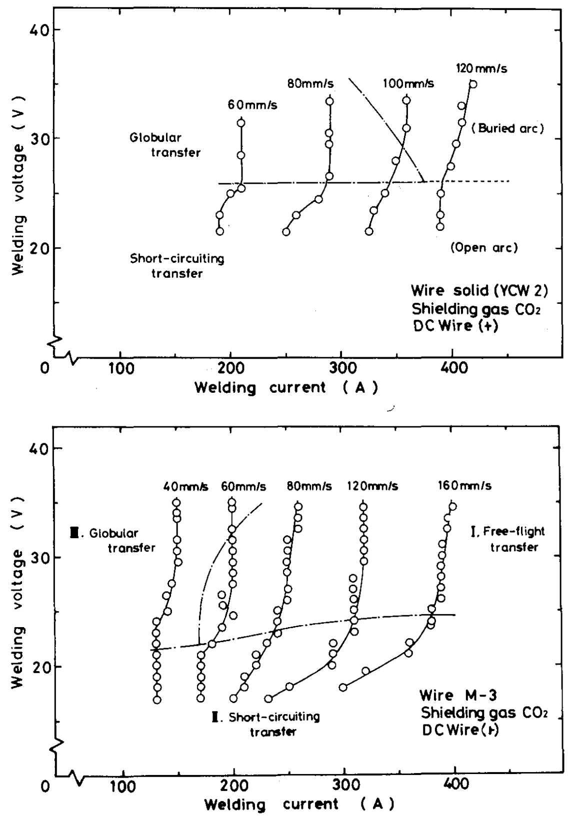


Fig. 3 Current and voltage characteristics of CO_2 welding arc with (a) solid wire and (b) flux-cored wire in various feeding rates (wire extension; 20 mm).

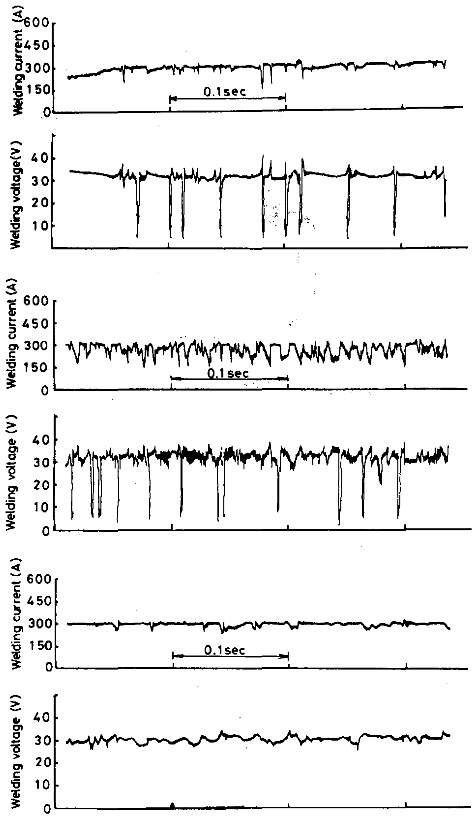


Fig. 4 Current and voltage wave forms at 300 A-30 V.

3.1.3 The relation between metal transfer and composition of shielding gas

Arc characteristics was investigated with various compositions of shielding gas. Arc phenomena which were observed with various compositions of shielding gas in solid, M-1 and M-3 wires are shown in **Photo 2.** With pure Ar, the electrode tips of M-1 and solid wires became tapered and spray transfer of fine droplet occurred. The metal sheath of electrode in M-3 wire was melt down faster than core material, and the core material formed the pole of flux (flux-pole). The molten metal was flown downward along the flux-pole after it detached from electrode tip. Under the same wire feeding rate, the length in the flux-pole decreased with increasing in the CO_2 content in shielding gas, because the melting rate of metal sheath is decreased with increasing in the CO_2 content.

The electorode tips of M-2, M-5 and M-7 wires with pure argon shielding are shown in **Photo 3**. The length in the flux-pole dimished with increasing in the iron powder content. As the content of iron powder in flux increased, the flux would have a conductivity in electricity, and then is heated and consumed during welding.

On the other hand, the metal droplets were transfered when the molten metal was moved down from the tip of

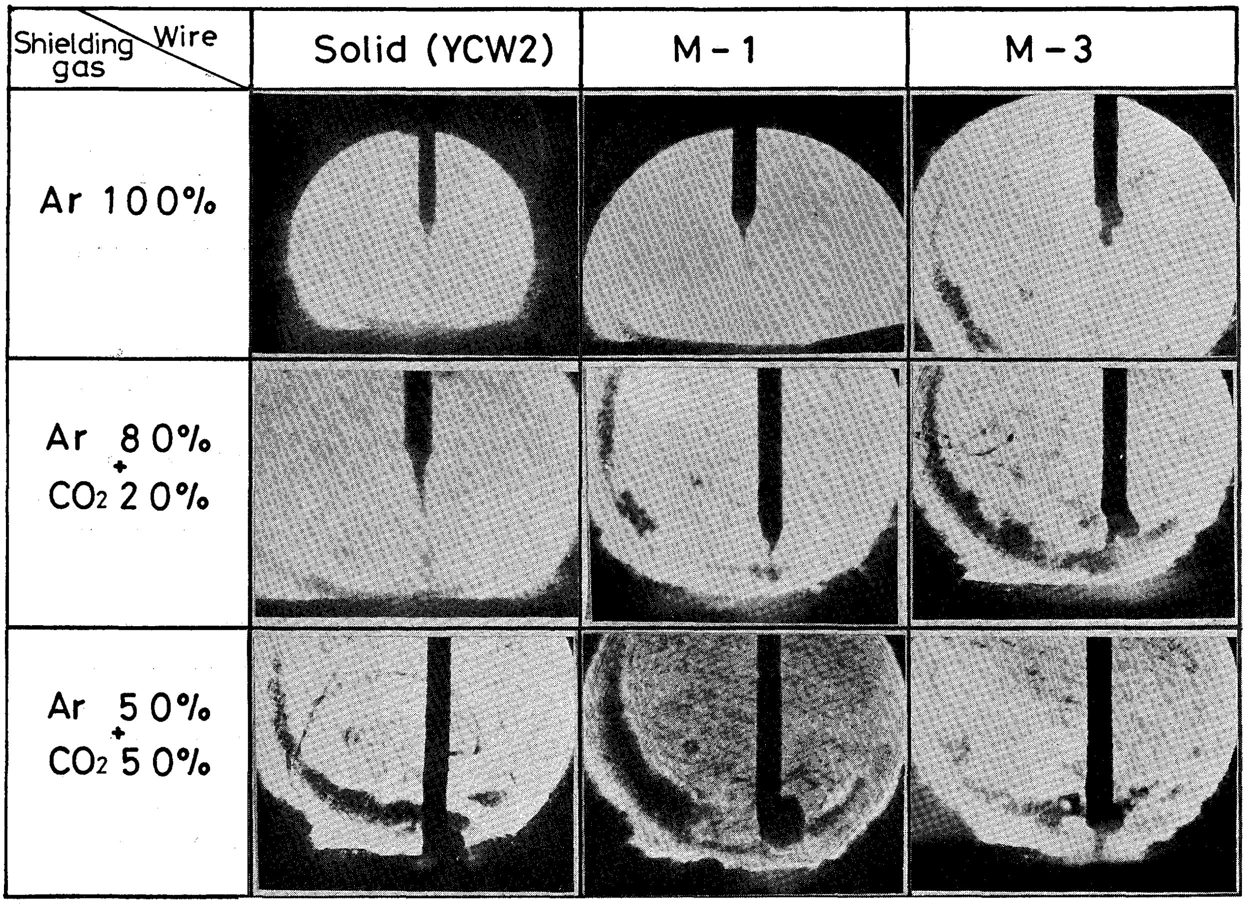


Photo 2 Typical example of electrode tips of solid, M-1 and M-3 wires.

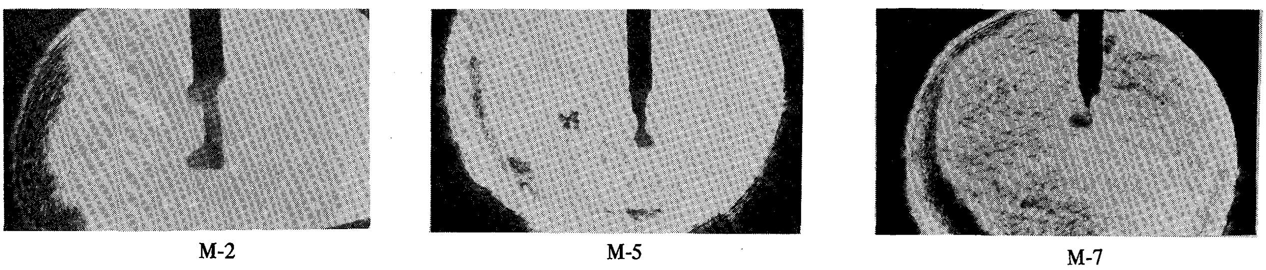


Photo 3 Typical example of electrode tips of M-2, M-5 and M-7 wires with Ar 100% shielding.

wire sheath, flew downward along the flux-pole and reached to its tip. Then the droplets tend to be fine as the flux-pole is shorter, because the molten metal is detached as soon as it moves from the tip of the metal sheath. Therefore, when CO_2 and Ar mixture gas is used for shielding gas with flux-cored electrode, the droplet can be small is size by possessing an electric conductivity in flux.

3.2 Distribution of size of droplet transfered

3.2.1 Influence of crosssectional shape in flux-cored wire

In flux-cored electrode with various geometrical shapes in crosssection, which was described in the previous report, distribution of the diameter of the droplets was shown in **Fig. 5** in case of Free-flight transfer mode. The droplet diameter tended to be a little smaller in wire A, B and C of fold-shape type in crosssection than in wire D and E of hollow-shape type. In solid wire, the droplet diameter was a large, because CO_2 is used for shielding gas.

The phenomena of the metal transfer of wire A for fold-shape type and wire E for hollow-shape type were investigated by the high speed 16 mm cine photography.

Each one example of them is shown in **Photo. 4**. In wire A, the molten metal was grown up and detached at two places separately at the electrode tip. On the other hand,

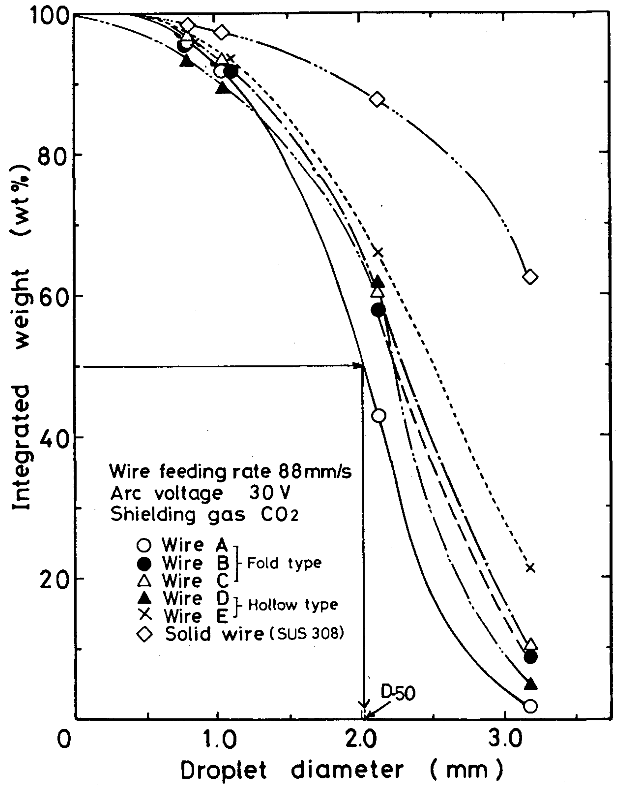
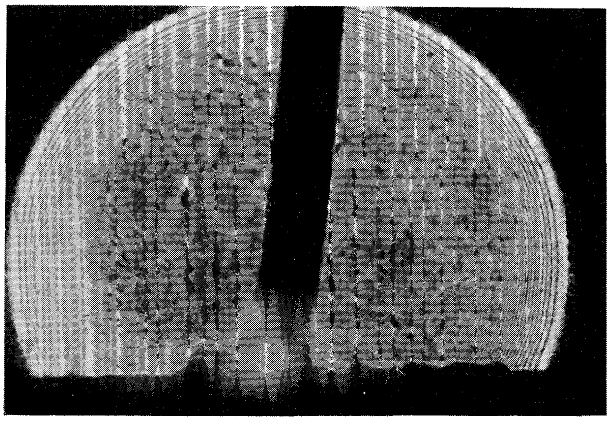
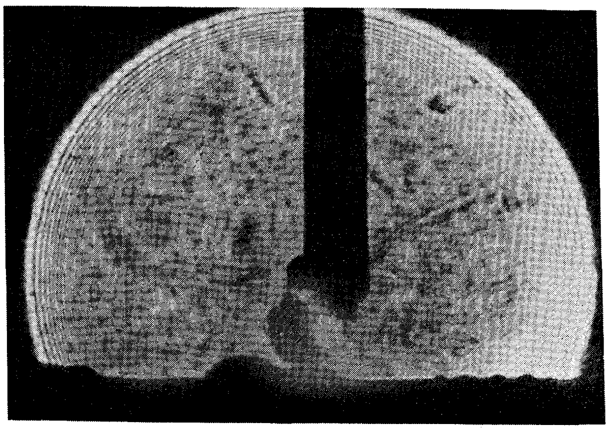


Fig. 5 Distribution of droplet diameter in flux-cored wires with various geometrical shapes in crosssection (Free-flight transfer).



(a)



(b)

Photo. 4 Typical example of electrode tips of (a) wire A and (b) wire E with CO_2 shielding at 300 A-30 V.

in hollow-shape type wire E, it could be seen that the molten metal tended to gather into one place arround the flux-pole, and it grew a large one and detached after the flew along the flux-pole either accompaning with or without flux.

There was an obvious difference in the metal transfer but there was a slight difference in the melting rate as shown in the previous report between wire A and wire B. Therefore the droplet diameter of the wire A was smaller than wire E due to an increase of the number of the droplet in wire A.

Nextly, in order to evaluate the size of the droplet in simple expression, the authors have designated the size D-50, which is the size in diameter of the droplet which shows the integrated weight of 50% as refered in **Fig. 5**. The relation between the droplet size D-50 and the welding current was shown for wire A and wire E in **Fig. 6** The droplet diameter is slightly decreased with increasing welding current in wire A. However, in the wire

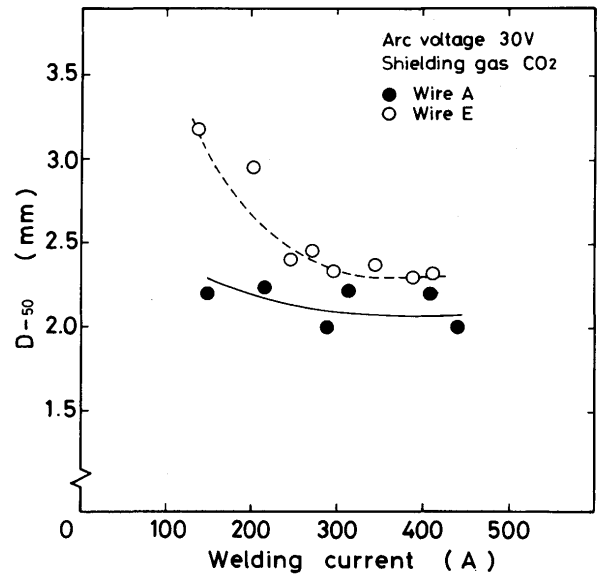


Fig. 6 Relation between D-50 and welding current with wire A and wire E (Free-flight transfer).

E of hollow-shape type, the droplet was abruptly increased in low welding current due to independent melting of the wire sheath. However, in fold-shape type wire A, the droplet diameter was small even in lower welding current. Therefore, it is found that the metal transfer of fold-shape type wire is stable for the wide range of welding current.

3.2.2 Influence of core material

The relation between the distribution of droplet diameter and the component of core material is shown for M-1, 3, 5, 7 and solid wires in **Fig. 7**. As shown in Fig. 7, it is evident that the droplet in flux-cored electrodes is

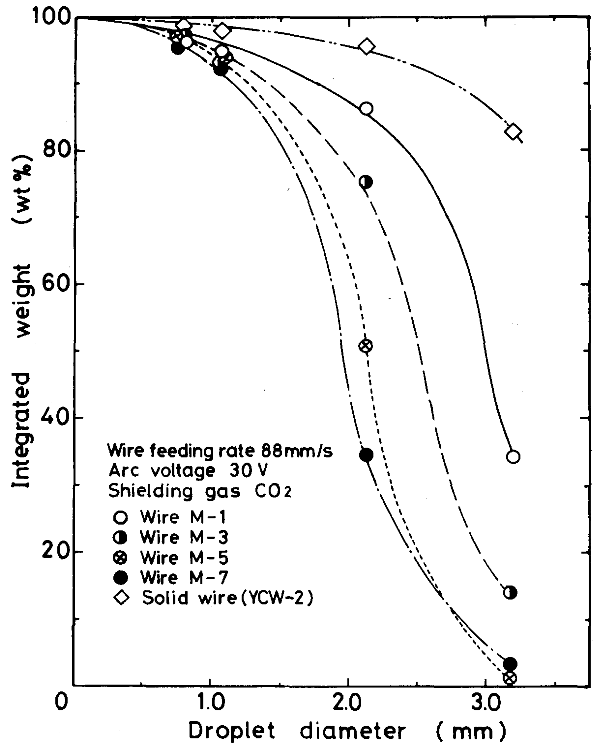


Fig. 7 Distribution of droplet diameter in flux-cored wires with various components of core material.

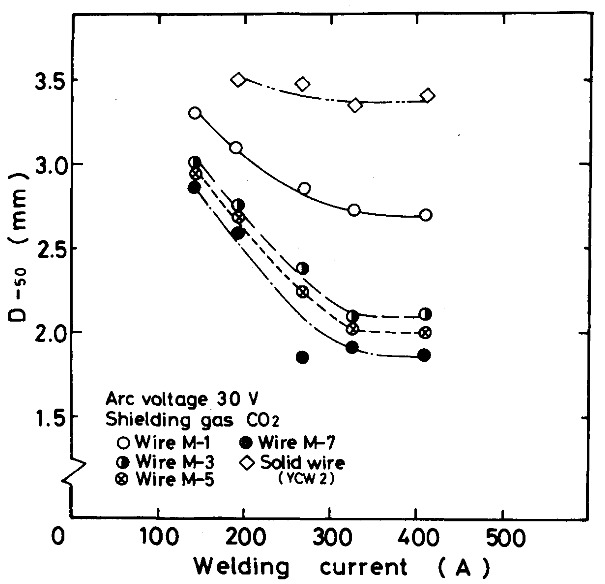
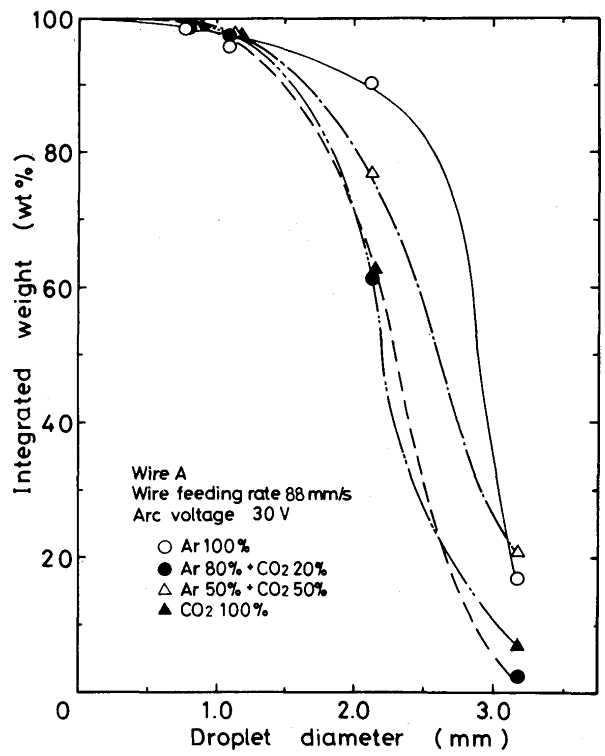


Fig. 8 Relation between D-50 and welding current in flux-cored wires with various components of core material.

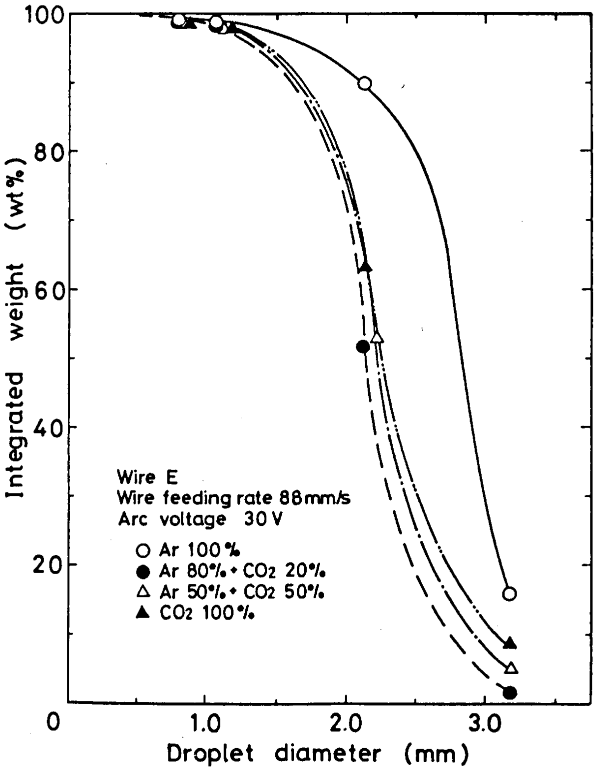
smaller than that in solid wire which occurs globular transfer. The values of D-50 under the various arc currents are shown in **Fig. 8**. It could be seen that the droplet diameter increases with a decrease in arc current and tended to be smaller with an increase in iron powder content in core material. This result was related to the length of flux-pole during welding, which has been described in the above. The length of flux-pole in wire M-7 was the shortest in the other flux-cored electrodes. In this wire, the droplet didn't transfer along the flux-pole, but transfered from the electrode tip due to neglegible small in length of the flux-pole.

3.2.3 Influence of shielding gas

When the component of shielding gas was changed to Ar 100%, Ar 80%-CO_2 20%, Ar 50%-CO_2 50% and CO_2 100%, the distributions of droplet diameter are shown in **Fig. 9 (a), (b)** and **(c)**. The relations between D-50 and CO_2 content (vol%) in shielding gas are reploted in **Fig. 10**, for A, E and solid wires. From these results, it can be concluded that the droplet diameter in solid wire increases in proportion to the increase in CO_2 content in shielding gas. That is to say, large size in CO_2 shielding gas due to globule transfer and very small size in Ar shielding gas due to spray transfer are seen. On the other hand, the difference between wire A and E of flux-cored electrodes in the droplet diameter is little and the diameter is seen to be almost constant against the composition of shielding gas. However one point is considered that the droplet in wire A and E is increased in case of pure argon shielding comparing to the other shielding gas. It is due to long length of the flux-pole in pure argon shielding welding. The molten metal which was formed in sheath of wire moved to electrode tip along the flux-pole gather-



(a) wire A



(b) wire E

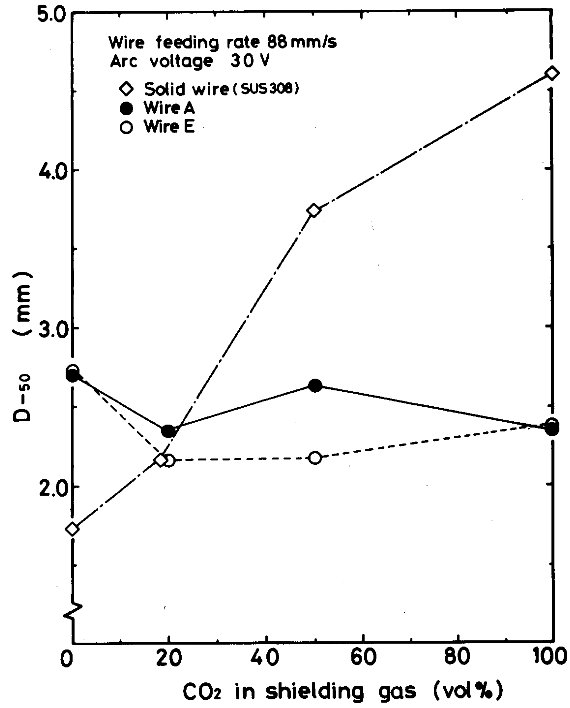
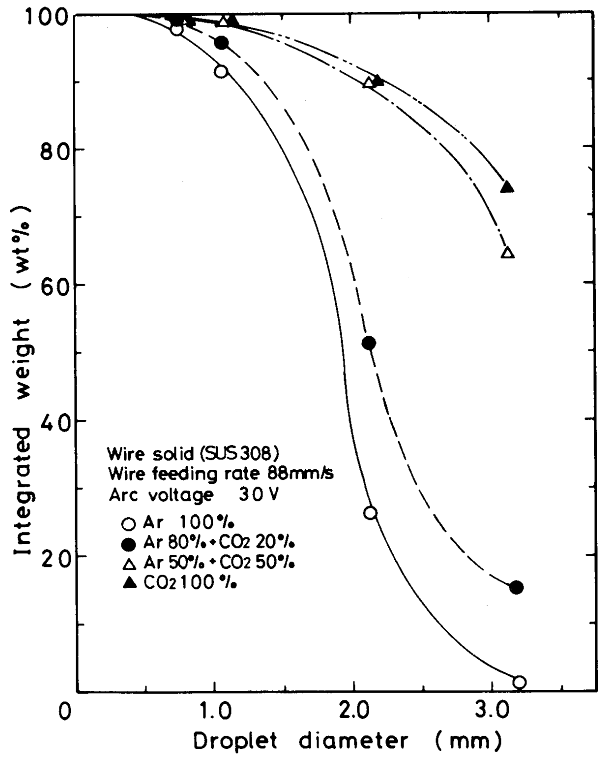


Fig. 10 Relation between D-50 and CO_2 content (vol %) in shielding gas with flux-cored wires.



(c) solid wire

Fig. 9 Distributions of droplet diameter with wire A, wire E and solid wire in Ar 100%, Ar 80% – CO_2 20%, Ar 50% – CO_2 50%, and CO_2 100% (Arc voltage 26 ~ 30V).

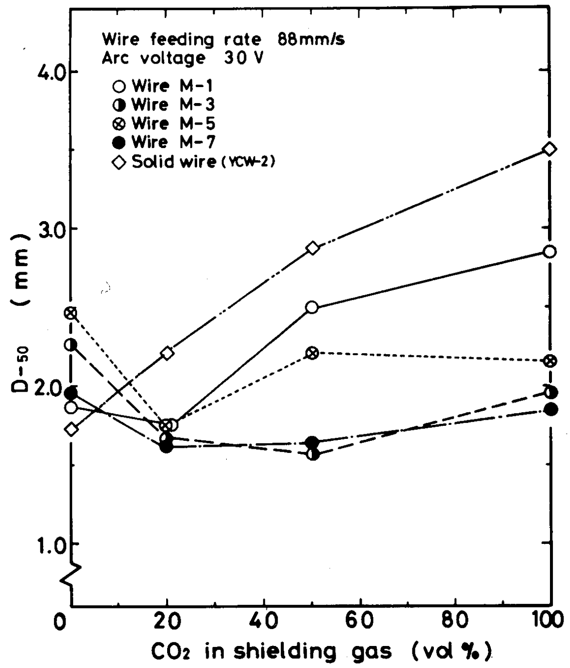


Fig. 11 Relation between D-50 and CO_2 content (vol %) in shielding gas with flux-cored wires.

ed arround its tip and detached from it. Therefore the droplet became larger in argon shielding. Moreover the relation between component in shielding gas and D-50 is shown in **Fig. 11** for the electrodes M-1 to M-7 with various component of flux-cored wire. The results showed the similar relationship to that in electrodes in Fig. 10. However it could be seen that the diameter of droplet obtained from the flux-cored electrodes containing a high amount of iron powder is smaller comparing to the other wires.

3.3 Chemical composition and porosity in weld metal

The chemical compositions and porosities in the weld deposited metal are collectively shown in **Table 3** for the welding conditions of the shielding gas of 100% CO_2 and 300 A-30V, 60 cm/min.

Table 3 Chemical composition and porosities in the weld metal

Wire	C	Si	Mn	P	S	[O]	[N]	Porosities
M-1	0.05	0.03	0.16	0.016	0.008	–	–	Yes
M-2	0.05	0.64	1.22	0.017	0.008	0.062	0.006	No
M-3	0.05	0.47	0.94	0.017	0.008	0.071	0.005	No
M-4	0.06	0.36	0.66	0.016	0.009	0.085	0.006	No
M-5	0.05	0.24	0.43	0.016	0.008	0.115	0.006	Yes
M-6	0.05	0.03	0.13	0.014	0.008	0.143	0.006	Yes
M-7	0.05	0.03	0.13	0.016	0.008	–	–	Yes
Solid 1.6	0.10	0.41	0.92	0.016	0.012	0.023	0.005	No

The oxygen content in deposited metal increases and Mn and Si contents decrease with an increase in iron powder content in core material, and the porosities increases with oxygen content. Therefore, the porosities observed when the deoxidation become poor, the limit in content of iron powder in core material is determined from Table 3, especially from porosities problem. This limit will be placed in 60% Flux-40% Iron powder in maximum which is designated as M-4 in Table 1.

4. Conclusion

(1) When the iron powder was added into core material in flux-cored wire, the melting rate decreases with increasing the content of iron powder under the same welding condition. This is due to reduction in the electric resistance of wire.

(2) With flux-cored wire, the melting of the flux inside the metal sheath is usually delayed to melt during welding and the pole of flux is seen on high speed cine film, for which we called flux-pole. The metal sheath melts arround it. The molten metal moves down along the flux-pole, as the sheath of metal melts, and detaches from its tip. The droplet size tends to decrease with decreasing in the length of flux-pole. The length of flux-pole was influenced with content of core material, welding condition and type of shielding gas, and it was decreased with increasing the content of iron powder in the core material and the shortest in 100% CO_2 gas shielding.

(3) When the component of Ar-CO_2 mixture gas was varied, the droplet size obtained was approximately constant in flux-cored electrode though it was a little increased in case of 100% Ar shielding. Moreover droplet size obtained in free-flight transfer mode with flux-cored electrode tended to be a little larger than that in spray transfer mode with solid wire though the difference is not so obvious.

(4) It could be seen that the droplet size in fold type wire tended to be smaller than in hollow type wire in free-flight transfer of 100% CO_2 shielding. The reason was considered from the high speed cine film that plural flux-poles were formed in the fold type wire during welding and the droplets were separately emitted from the each flux-pole.

(5) From the results of the analyses of the chemical composition and the inspection of porosities in the deposited metals of various flux-cored wires, the ratio of iron powder to flux in core material is recommended to be less than 40% in the range of this study due to increasing of oxygen and porosities.

Acknowledgement

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References

1) F. Matsuda, et al: Trans. JWRI, Vol 8 (1979), No.2, p.189.
2) K. Ishizaki, et al: "A Method of Evaluating Metal Transfer Characteristics of Welding Electrode", Physics of the Welding Arc Symposium, London, 1962.