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Citation	Transactions of JWRI. 1981, 10(2), p. 153-161
Version Type	VoR
URL	https://doi.org/10.18910/9226
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GMA Welding of 9%Ni-Steel with Similarly Composed Nickel Alloy Wire in Helium Shielding†

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Abstract

The development of welding method of 9%Ni-Steel GMA welding (DCRP) with similarly composed nickel alloy wire through the study on the instability of welding arc based on the aspects of arc roots is described. Under the conditon of open arc in inert atmosphere, cathode spots move erratically and irregularly on the plate surface in front of weld pool, and it results in unstable welding arc. The addition of oxygen to argon shielding gas causes the concentration of arc roots in the narrow region right under the arc column, and the increase in melting efficiency of base metal and in oxygen content in the weld metal. On the otherhand, under the condition of burried arc with constant voltage power supply, the arc roots are confined in the well in the weld pool. With helium shielding fairly good weld metal and bead configuration are obtained. Very small blow holes apt to appear at the root of fuzed zone, but they are effectively decreased by applying the fast transverse weaving of welding arc.

KEY WORDS: (GMA Welding) (He Shielding) (Stability) (Cathode Spot) (Weaving)

1. Introduction

In the GMA welding of 9%Ni-Steel which is a material for the fabrication of cryogenic storage vessels, the use of a similarly composed nickel alloy wire instead of the high nickel alloy wire has been eagerly investigated. However, the GMA weld metals with the similarly composed nickel alloy wire of about 9 to 11% in nickel content have an inferior property in ductility at LNG temperature so far. One of main reasons in the above is the high oxygen content in the weld metal, which is caused by absorption of the oxygen in shielding gas of Ar-O_2 or Ar-CO_2 mixture.[1] The O_2 or CO_2 gas of about 3 to 25% in volume is generally added to argon shielding gas to stabilize the welding arc.

In order to obtain good weld metal ductility it is essential that the welding is carried out in a relatively inert atmosphere. Consequently, the effect of oxygen on the stability of welding arc are studied with the objective of determining a minimum O_2 requirement.[2] But the oxygen content in the weld metal is highly sensitive to the amount of addition of O_2 to the argon inert shielding gas.

Therefore, the development of the GMA welding method for 9%Ni-Steel with the similarly composed nickel alloy wire in the inert atmosphere is needed[5].

The purposes of the work to be described in this paper are as follows;

1) to make clear the aspects of arc root behavior in connection with the stability of welding arc,
2) to show the possibility to obtain good weld metal and bead configuration with He shielding.

2. Experimental Apparatus and Materials Used

Chemical compositions of materials used in this experiment are shown in **Table 1**. Two kinds of materials are used, which are 9%Ni-Steel and Mild-Steel. The diameter of the filler wire is 1.2 mm. The base metal has a thickness of 12 mm, a width of 100 mm and a length of 200 mm and its surface is carefully ground to be substantially oxide free before welding.

Conventional bead-on weldings are made with electrode-positive (D.C.R.P.) polarity using the transistorized

† Received on October 9, 1981

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

power supply whose characteristics are shown in **table 2**.

Gas flow rates of shielding gas are 24 l/min in almost cases but 50 l/min in the case of He shielding. The welding torch is held vertically downwards separated by 20 mm above the plate, and the distance between the lower edge of contact tip and the plate surface is also fixed at 20 mm. The inner diameter of shielding nozzle of the torch is 22 mm.

The plate is moved horizontally at the constant speed of 40 cm/min except for the case of He shielding.

The arc column and the behavior of cathode spots on the plate surface are observed by the use of high-speed cine-camera. Simultaneously, the arc current and out put voltage of welding power supply are measured using the electromagnetic oscillograph with a maximum frequency response of 2 kHz. Oxygen and nitrogen contents in the filler wire, the base metal and the weld metals are chemically analyzed by LECO apparatus.

3. Aspects of Arc Root Behavior

Cathode spot is the arc root on the cathode plate surface characterized by small spot area with high electric and thermal field, high current density relative to those of arc column and strong plasma jet outflow. In the D.C.R.P. GMA welding of non-refractory metal with inert gas shielding, similar cathode spots observed on the surface of base metal as many high luminous points with strong vaper jet outflow. Those spots move around rapidly and erratically and the behavior appears to give a significant effects to the melting of work piece, the transfer of metal across the arc column, the configuration of weld bead and the electrical stability of the system[2].

3.1. Electrical stability and external characteristics of power supply

A preliminary experiment on the effect of the external characteristic of power supply (characteristic line of load) on the stability of the welding arc in argon shielding gas is made under the following welding conditions.

Two typical external characteristics of power supply, constant current power supply (C.C.) and constant voltage power supply (C.P.), are applied to the same operating condition of welding (welding current: 250 A, welding voltage: 32 V, wire feeding rate: 5.7 m/min, open arc and spray transfer mode).

Changes in fluctuations of arc length, arc voltage and arc current with above two typical power supplies are observed. When the constant current power supply is applied, the arc length which is effectively evaluated by the distance between the end of wire and the surface of the molten pool, is kept relatively constant compared with that with constant voltage power supply, in spite of the very similar behaviors of arc roots movements in both cases. With the constant voltage power supply, the erratic and irregular motion of the arc roots causes the perturbation in welding current, and results in the fluctuation of melting rate of the feeded wire.

Table 1 Chemical compositions of base and filler wire metals used (wt %)

(9%Ni-Steel)	C	Si	Mn	P	S	Ni	Cr	Ti	Al	N	O
Base metal	0.05	0.22	0.44	0.004	0.003	8.75	0.03	<0.01	0.02	0.0057	0.0023
Wire metal	0.03	0.01	0.38	0.003	0.003	11.08	0.02	<0.01	<0.01	0.0022	0.0055

In this investigation, Mild-Steel : SM-41B is also used.

Table 2 Main characteristics of power supply

Output	Current 800 A (max). Voltage 45 V (max).
External characteristics	Constant voltage 0.3 V/100 A Constant current 0.08 A/V Drooping 0.5 – 100 V/100 A
Frequency response	30 kHz (max).
Wave forms	D.C. Modulated D.C. (by following wave form) Sinusoidal wave Triangular wave Rectangular wave

In order to examine the feature of arc root behavior, it is convenient to hold the effective arc length and arc current to be constant, so we use the constant current power supply and open arc welding conditions in the experiments to be described in this chapter.

3.2. Cathode-spot-area and arc root behavior

In a previous paper, it is shown that in the GMA welding with argon shielding the cathode spots on the plate surface move randomly and rapidly over the broad area out of the weld pool. The formation and development of those cathode spots are associated with the fluctuations of arc column. And, it causes the instability in mode or direction of metal transfer, which results in irregular configuration of weld bead.[2]

Here, the traces of moving around of the cathode spots, are examined by using a scanning electron microscope (SEM). As shown in **Fig. 1**, a broad and whitish area which

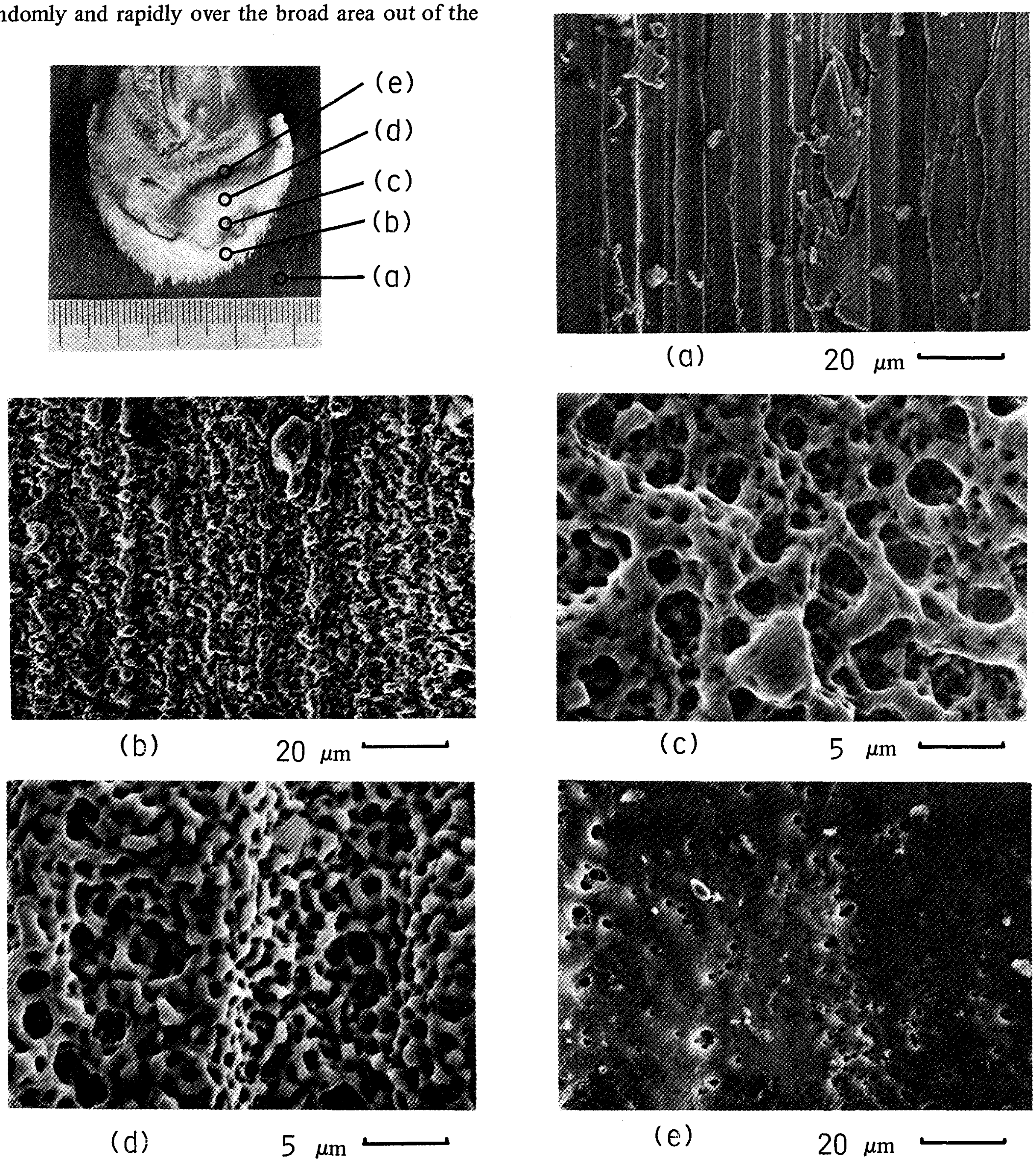

Fig. 1 Appearances of surface of cathode-spot-area around weld pool Welding condition (welding current; 350 A, welding speed; 40 cm/min, argon gas flow rate; 24 l/min, material; Mild Steel).

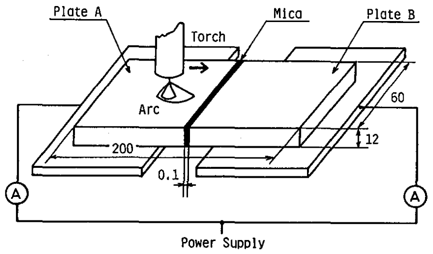

Fig. 2 Experimental setup to examine electric current flowing into cathode spots in front of weld pool. Welding arc travels from (A)-Side to (B)-side. Welding condition (Welding current; 350 A, welding speed; 40 cm/min, argon gas flow rate; 24 l/min, material; Mild Steel.)

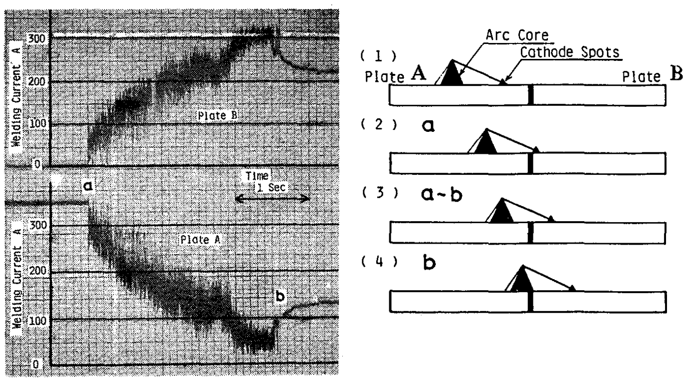

Fig. 3 Time-variations of electric currents flowing into plate (A) and plate (B) simultaneously measured. Corresponding changes in arc configuration are also shown schematically.

has apparently different tone in glossiness from that of base metal surface exists around the weld bead. This area is the one in which cathode spots move around during welding. In the (a) area where the arc cathode spot can not reach, many tracks of grinding of plate surface before welding are observed. In the areas (b), (c) and (d), many craters whose diameters are $2 \sim 3\mu$m in (d) and below 5 μm in (c), can be seen. The metal around the craters has roundish appearance without sharp edge in those area and it obviously shows that the plate surface was melted with the arc root or cathode spot formation and development. In the region (e) near the front edge of weld pool, can not be found out so many craters. This relatively flat area may be explained as the molten metal filled up some of the craters.

These craters can be regarded as the traces of cathode spots and as seen in the investigations on the vacuum arc electrode[3)], these craters are thought to be the traces of emitting sites of electrons and metal vapor because of similarity in size, shape and overall appearances.

Next, in order to examine the electric current flow into the cathode spots, following experiment was carried out. **Figure 2** shows the experimental procedure. Two cathode plates are placed in a line with a gap of 0.1 mm, in which a mica insulating sheet is inserted. If the electric currents flowing into the two cathode plates can be separately measured, by travelling the welding arc from the plate (A) side to the plate (B) side, electric current to the cathode spots existing on the plate (B) can be discriminately measured.

This experiment was done by using the Mild-Steel and under the GMA welding condition of 350 A in welding current, 36 V in welding voltage and 9.6 m/min in wire feeding rate in argon gas shielding. The result is shown in **Fig. 3.** When the arc roots reach the plate (B), electric current begins to flow in plate (B). And in a instance of electrical connection due to the bridging of the molten metal in the weld pool to the plate (B), two currents become to settle the equilibrium values. The electric current flowing into the plate (B) in the time interval from **a** to **b** is the current to cathode spots existing in front of the weld pool.

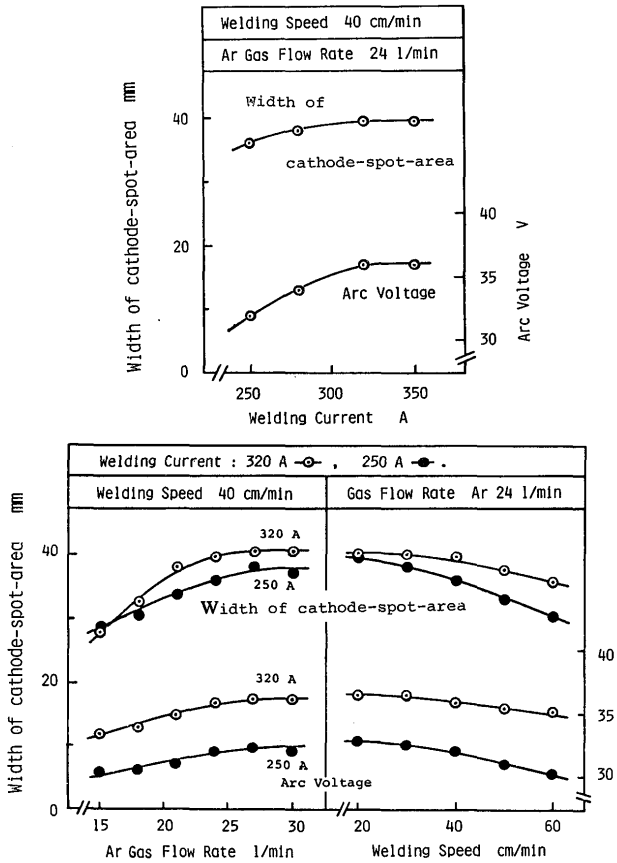

Fig. 4 Changes in width of cathode-spot-area under various conditions of welding current, argon gas flow rate and welding speed.

It is shown that almost all current flow into the cathode spots and not in the molten pool, despite that the major part of heat input is transported to the molten pool. Moreover, it is thought that almost all spots exist in a semicircle

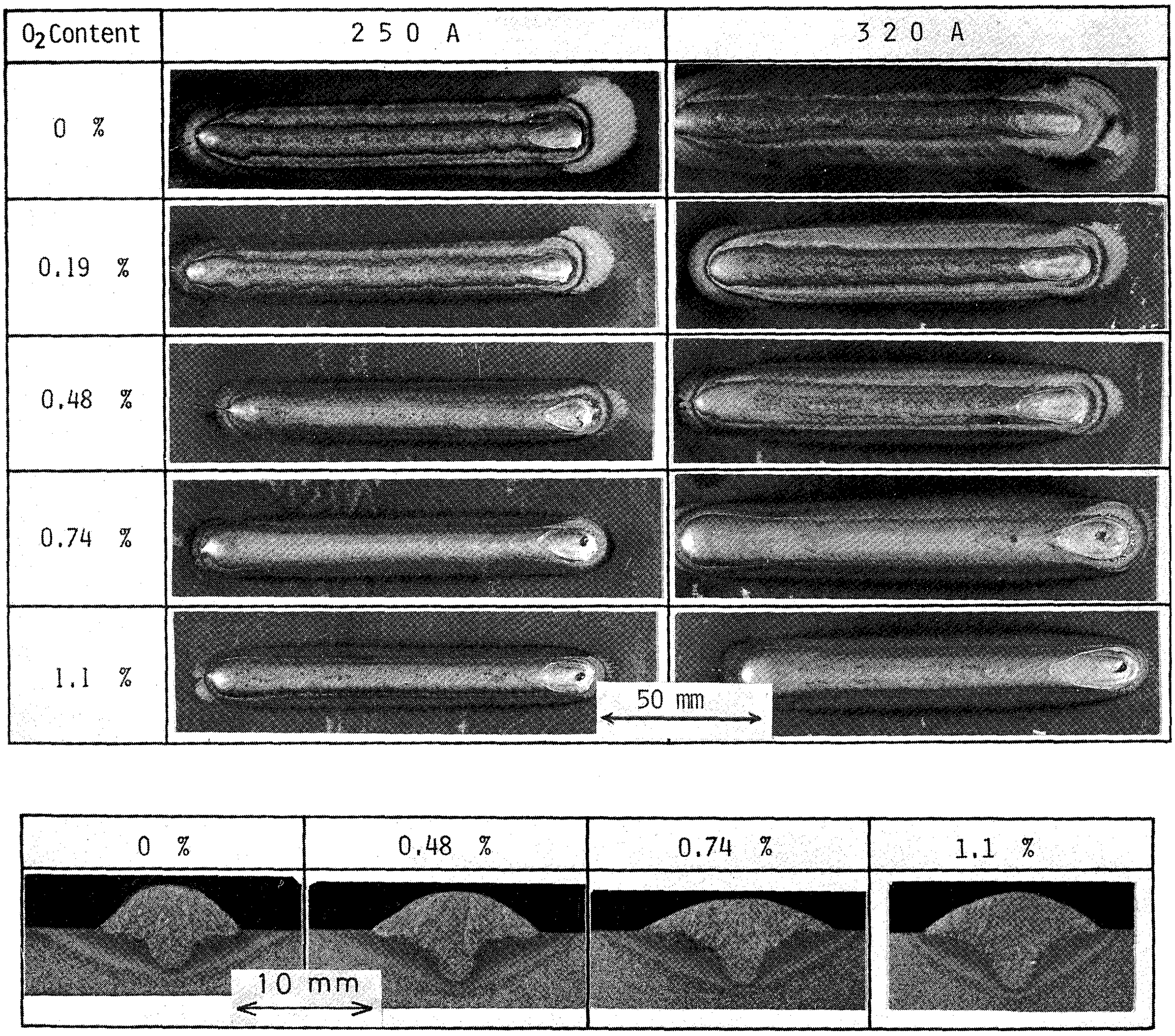

Fig. 5 Bead appearances under various conditions of oxygen addition to argon shieding gas (welding current: 250A and 320A, welding speed: 40 cm/min, argon gas flow rate: 24 l/ min.) Cross sections in cases of 320 A in welding current are also shown.

area in front of the weld pool. The heat input to the pool surface is considered to be transported by the droplets of molten wire metal and the convective arc flow mainly, but the heat transfered by electric current is widely distributed over the broad cathode-spot-area.

Finally, the width of the eroded area, that is, cathode-spot-area was measured under various welding conditions. If the oxide film is formed in advance on the plate surface, so-called cleaning action, means the removal of oxide due to the cathode spot formation, occurs. However, with oxide-free surface, the surface erosion or melting associated with the formation of cathode spot is the main occurrence. **Figure 4** illustrates the plots of the width of cathode-spot-area and the arc voltage under various conditions of arc current, argon gas flow rate and welding speed. The increase in the width is accompanied with the increase in welding current and gas flow rate and the decrease in welding speed.

3.3. Effect of oxygen on arc root behavior

In order to examine the effect of oxygen on arc root behavior in GMA welding, very small amounts of oxygen are added to the argon shielding gas. **Figures 5** and **6** show significant decrease in the width of cathode-spot-area due to the addition of O_2 of $0.25 \sim 1.0\%$ in volume to shieding gas. In those cases the visible cathode spot can not be seen clearly but it is though there is a large number of coexisting individual arc roots spread diffusely over a "cathode area", limited narrow area right under the arc column. According to the observation of cathode spots with reverse-polarity GTA welding (D.C.R.P.), visible cathode spots located at the edge of weld pool and the diffused arc roots on the surface of the pool can be found out, as shown in **Fig. 7**. The formation of oxide film and the craters which are believed the traces of cathode spots are observed in **Fig. 8.** This appearance is also very similar to that appeared in the

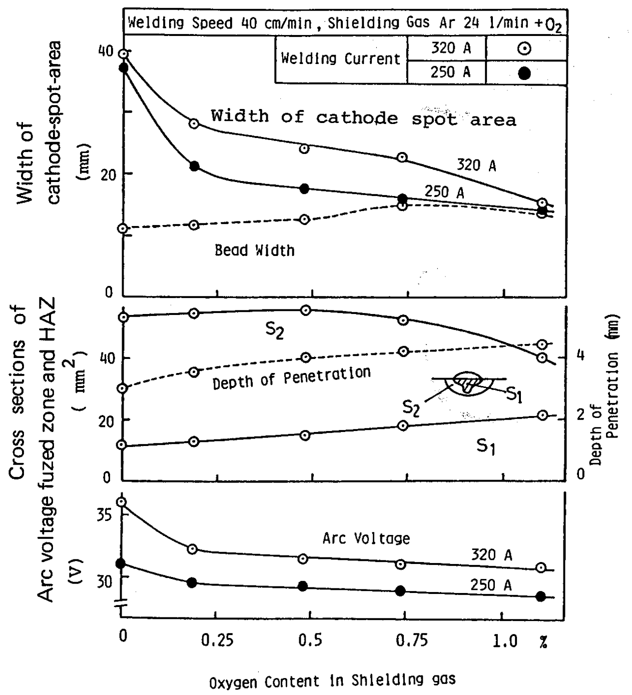

Fig. 6 Changes in arc voltage, width of cathode-spot-area, depth of penetration and cross sections of fuzed zone and heat affected zone under various conditions of oxygen addition to argon shielding gas.

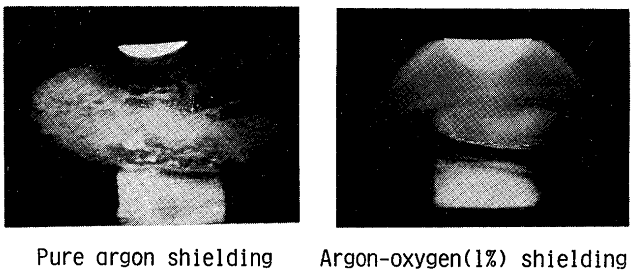

Fig. 7 Photographs of cathode surface of D.C.R.P. GTA arc showing the difference between formation of arc roots in pure argon shielding gas and that in argon-oxygen mixture shielding gas.

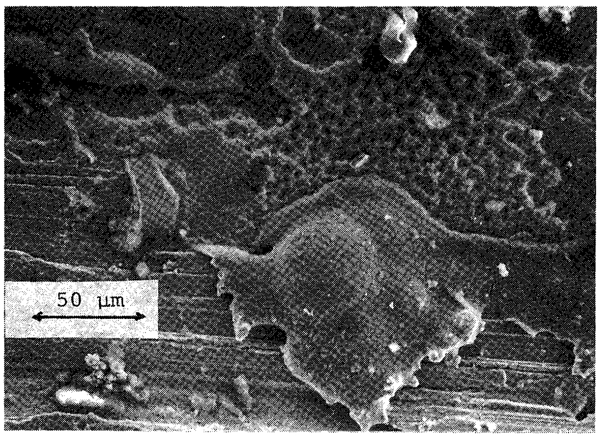

Fig. 8 Appearance of cathode-spot-area in the vicinity of weld pool in the case of GMA welding with argon-oxygen (1%) mixture gas shielding. Formation of oxide film and craters showing the traces of cathode spot can be seen.

vacuum arc electrode with oxide film[3].

It is evident that the configuration of weld bead is fairly good by the addition of oxygen of 0.7 ~ 0.8% in volume. Moreover, the depth of penetration and the cross sectional area of fused zone both increase with increase in oxygen addition. Cross section of fused zone in the case of 1.1% oxygen addition is two times larger than that in the case of pure argon, in spite of the decrease in arc power due to the decrease in arc voltage. The concentration of arc roots in the narrow region by the addition of oxygen increases the melting efficiency of base metal, though the reason is not yet clear.

The change in oxygen content in the weld metal with various amounts of added oxygen in the argon shielding gas are shown in **Fig. 9**. The nitrogen contents in the weld metal are held constant under various conditions of oxygen addition. It suggests the shielding of the weld metal from air is fairly good and the increase in oxygen content in the weld metal is due to the increase in the absorption of oxygen in shielding gas. The increase rate in oxygen content in weld metal becomes large at the point of 0.7% addition of oxygen for the Mild-Steel and at the point of 0.3% for the 9%Ni-Steel. At this point the generation and removal of the oxide film might be in equilibrium. The values are relatively small but may depend on the amount of deoxidizer including in base and wire metals. In any case, the oxygen content in weld metal is highly sensitive to the amount of added oxygen in the argon shielding gas in such a region of small amount addition.

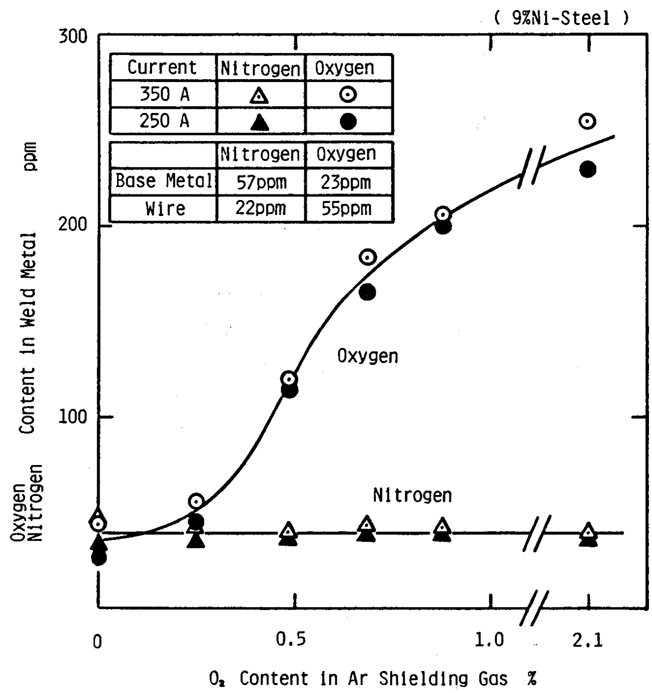

Fig. 9 Oxygen and nitrogen contents in weld metal in various cases of oxygen content in argon-oxygen mixture shielding gas.

From some experiments above mentioned, it follows that;

1) The concentration of the cathode spot or arc root in the limited narrow region increases the stability of welding arc, regularity of configuration of weld bead and thermal efficiency.
2) Cathode spot could not formed on the surface of weld pool in the mode of open arc in argon shielding gas without addition of material which functionates as the cathode.
3) In order to suppress the oxygen content in weld metal to the low value like 50 ppm, it is essential that the welding is carried out in a oxygen-free atmosphere such as argon, helium and so on.

4. GMA welding of 9%Ni-Steel in Helium Shielding

4.1. Preliminary consideration

Helium gas has high thermal conductivity, high ionization potential and low viscosity compared to those of argon. Due to those features, the localization of the arc root in the narrower region, high melting rate of the wire and the globular transfer mode of the molten droplet will be realized. As mentioned in the preceding section, in the open arc mode with argon shielding the cathode spots can not be concentrated on the surface of the weld pool and its vicinity. One of the possible ways to concentrate the cathode spots in the narrower region near the wire electrode is to realize the so-called burried-arc[4]. So, two cases of welding arc are examined, those are the open arc and the burried arc.

Firstly, by using the He-Ar mixture gases for shielding, bead-on welding were made and measured the width of cathode-spot-area. Welding condition was as follows; the arc was open arc whose effective length was 4 mm, the arc current was 250 A and the constant current power supply was applied. The results are plotted in **Fig. 10**. The metal transfer mode in the region from 100% to 20% in argon content in shielding gas was the spray mode, but becomes the globule mode with increase in helium content. The most important in this experiment was that the welding arc was evidently unstable though the width of cathode-spot-area was significantly decreased.

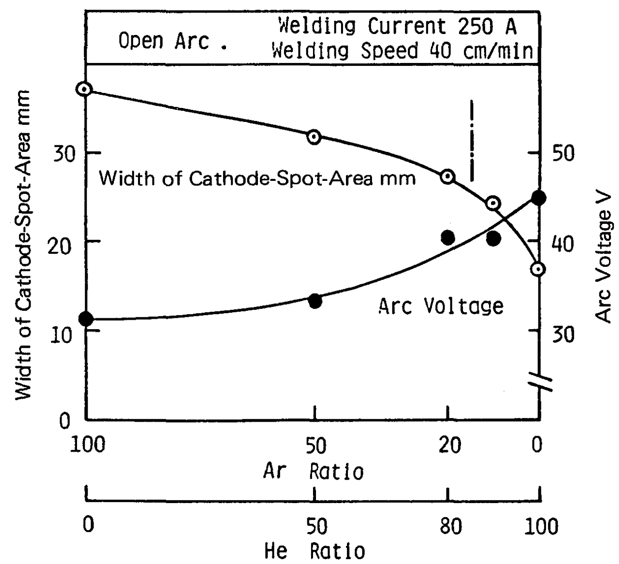

Fig. 10 Changes in width of cathode-spot-area and arc voltage under various mixing condition with argon and helium for shielding gas.

4.2 Burried arc welding in helium shielding

Figure 11 shows the current and voltage characteristics in relatively high feeding rate of wire. The burried arc in helium shielding was examined with the constant voltage power supply. In the case of burried arc, the wire electrode get in the well formed in the molten pool. The arc is generated in the well and cathode spots can not be found out on the plate surface. Occurrence of the spattering of molten metal was extremely rare and good configuration of weld bead is obtained.

Cross sections of bead are shown in **Fig. 12** under the various welding conditions. With a constant feeding rate of wire, the increase in welding voltage increses the bead width but causes no appreciable change in the penetration depth. On the otherhand, with constant welding voltage, the increase in wire feeding rate increases the penetration depth through the increase in welding current.

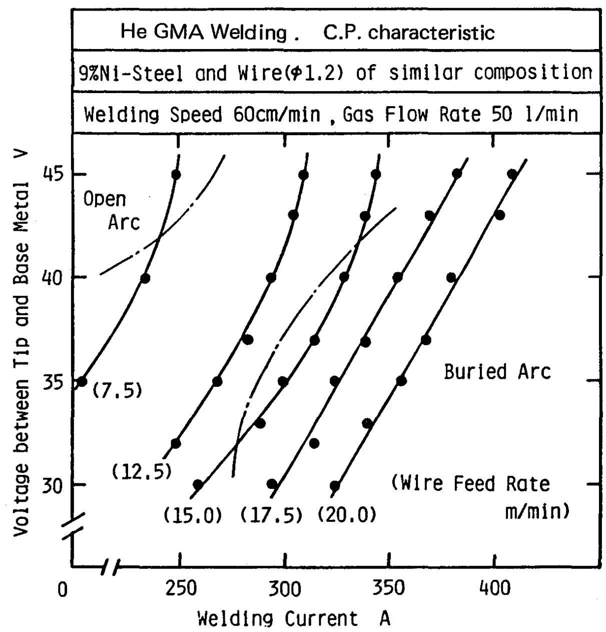

Fig. 11 Current and voltage characteristics of GMA welding arc with helium shielding in relatively high feeding rates of wire and classification of arc configuration.

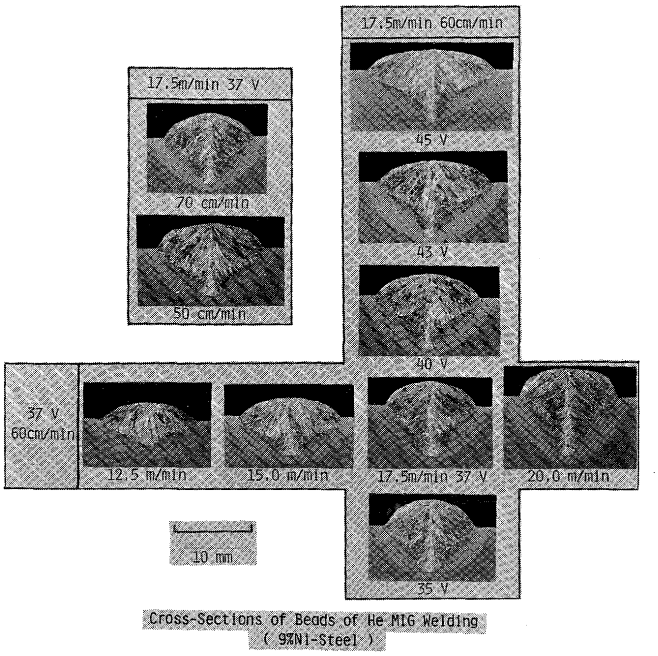

Fig. 12 Appearances of weld cross sections under various welding conditions of burried arc with helium shielding.

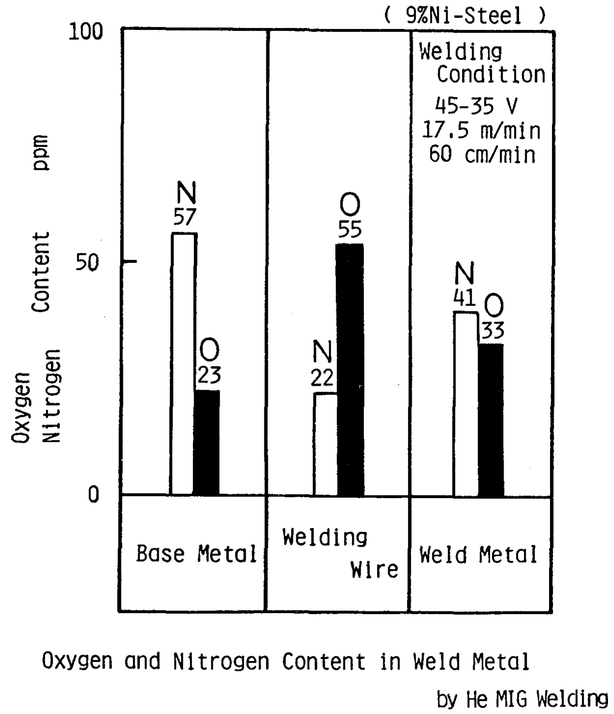

Fig. 13 Oxygen and nitrogen contents in the base metal, the wire metal and the weld metal.

The oxygen and nitrogen content in the weld metal are compared with those in the base metal and wire metal in **Fig. 13**. The value in the weld metal is satisfactorily low. These results show the fairly good shielding effect by helium gas.

But, the nondestructive examination by X-ray revealed the existence of many small blow holes at the root of the fuzed zone. The size is all below about 1.0 mm in diameter. In order to reduce the formation of blow holes, the fast transverse weavings[6] of welding torch were applied under the conditions of 5 to 20 Hz in frequency, 2 to 6 mm in amplitude. X-ray radiographs of weld for the non-weaved and weaved cases are shown in **Fig. 14**. By applying the suitable weaving, the sound weld is obtained.

It should be noted that these results manifest the possibility of the satisfactory GMA welding of 9%Ni-Steel with similarly composed nickel alloy wire under the condition of burried arc with helium gas shielding.

5. Conclusions

In this paper, through the study of the stability of welding arc based on the aspects of arc cahode roots, the development of the welding method of 9%Ni-Steel GMA welding with similarly composed nickel alloy wire was described.

A summary of the results obtained is as follows: On the aspects of arc cathode roots of GMA welding,

1) Almost all the welding current flows into the cathode spots.
2) Cathode spots are formed on the plate surface in front of the weld pool with inert gas shielding, but, the surface of the weld pool and its vicinity is the "cathode-spot-area" with argon-oxygen mixture gas shielding.
3) The traces of irregular and erratic motion of the cathode spot appears to be eroded and melted. In its area, "cathode-spot-area", there are many craters and these considered to be the emitting sites of the cathode spot.
4) The addition of oxygen to argon shielding gas causes the concentration of arc roots in the narrow region right under the arc column, the increase in melting efficiency of base metal and the increase in the oxygen content in the weld metal.

On the GMA welding in helium shielding gas,

1) The GMA welding in electrode-positive polarity with helium shielding, under the condition of burried arc with constant voltage power supply, the arc cathode roots are confined in the well in the weld pool. And fairly good bead configuration is obtained. The oxygen content in the weld metal is below 50 ppm, but very small blow holes apt to appear near the root of the weld. Those blow holes are effectively decreased by applying the fast transverse weaving of the welding arc.

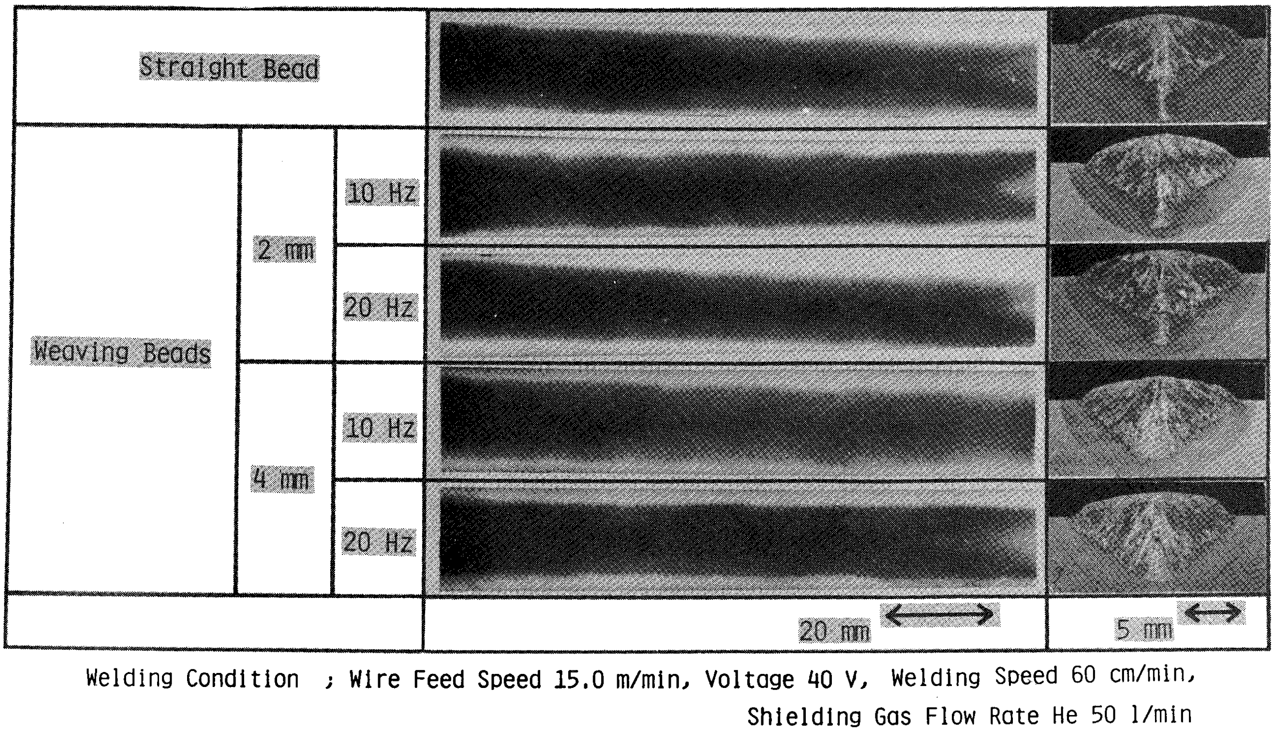

Fig. 14 X-ray radiographs showing effectiveness of fast transverse weaving of welding arc on reducing the formation of blow holes. Applied weaving conditions are 10 and 20 Hz in frequency and 2 and 4 mm in amplitude.

Acknowledgement

The authors would like to thank Mr. S. Oshima, Chief Engineer, Matsumoto Kikai Co. Ltd., for the help in applying the fast weaving of welding arc.

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