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Effect of Oxygen on Stabilization of Arc in 9%Ni-Steel GMA Welding†

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Abstract

Unstable phenomena of welding arc in DCRP GMA welding of 9%Ni-Steel with a similarly composed nickel alloy filler metal in commercially pure argon gas shielding are observed with a high speed cine-camera. Two types of unstable phenomena appear in the arc during welding. One is the fluctuation of the arc column associated with the erratic behavior of the arc roots on a plate surface under the higher arc voltage condition and the other is the alternation between spray transfer mode and short-circuiting arc dip transfer mode under the lower arc voltage condition. These unstable phenomena can be stabilized by the adding of O_2 or CO_2 gas to argon gas shroud or by the use of pre-oxidized surface as the cathode plate, which narrow the "cathode area" and smear the cathode spots diffusively over this area. Minimun O_2 or CO_2 gas content in argon shielding gas necessary for stabilizing the arc is 0.3 ~ 0.5% or 0.7 ~ 1.0% respectively. These minimun values are significantly low and make it possible to suppress the oxygen content in the weld metal to the one below 100 ppm.

1. Introduction

In the GMA welding of 9%Ni-Steel which is a material for the fabrication of cryogenic storage vessels, high nickel alloy wires such as Inconel 61, 81, Monel 60, etc., have been widely used as a filler wire. Using those wires the conventional GMA process has been applied mainly with short-circuiting arc dip transfer mode in helium shielding.

Following the development of GMA pulse welding, the new process was investigated in connection with the claim that is overcome the lack of fusion encountered during dip transfer welding in the conventional one, and thus satisfactory deposited metals were made on 9%Ni-Steel at present.[1]

However there are some fundamental disadvantages in the welding of 9%Ni-Steel using a high-nickel alloy welding filler wire which are high cost of filler wire due to high nickel content, high sensitivity to hot cracking of weld metal, low mechanical strength of weld metal in comparison with base metal, great difference in thermal expansion coefficient between weld and base metals and so on.

Therefore, it is eagerly expected that the use of a similarly composed nickel alloy wire instead of high-nickel wire for the welding of 9%Ni-Steel.

However the GMA weld metals with a similarly composed nickel alloy wire of about 9 to 10% nickel content have an inferior property in ductility at the LNG temperature. One of main reasons in the above is due to high oxygen content in the weld metal which was caused by the absorption of oxygen in shielding gas of argon-O_2 or argon-Co_2 mixture. The O_2 or CO_2 gas in argon shielding gas is generally added to about 3 to 25 percent in volume in order to stabilize the welding arc. Therefore, the development of pure argon shielding GMA welding without O_2 or CO_2 gas addition whose arc is also stabilized will be expected for the welding of 9%Ni-Steel in order to obtain the high ductile weld metal using the similarly composed nickel alloy wire.[2]

Therefore the aim of this work is to observe the unstable phenomena of the arc in the conventional GMA welding of 9%Ni-Steel with the similarly composed nickel alloy wire (10%Ni) in pure argon shielding and to investigate the effect of O_2 or CO_2 added to shielding gas on the arc instability.

2. Experimental procedures

Chemical compositions of material used in this investigation are shown in Table 1. The content of oxygen in the wire is about 70 ppm and titanium, aluminium and chromium are not comprised. The diameter of the filler wire is 1.2 mm. The base metal has a thickness of 10 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 using the commercial automatic welding machine whose power source has a drooping characteristic of about 3.5V /100A. A welding torch is reconstructed so that

† Received on March 31, 1978
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Table 1 Chemical compositions of base and filler wire metals used. (W T%)

	C	Si	Mn	P	S	Ni	Al	N	O
Base metal	0.046	0.21	0.50	0.013	0.007	9.28	0.042	0.0052	0.0015
Wire	0.040	0.17	0.45	0.001	0.003	10.43	—	0.0009	0.0070

too, in order to prevent air to be introduced into the argon shroud through the wire feeding system. This flow is 0.05 l/min in rate, which is negligible compared with main shielding gas flow of 25 l/min in rate.

The torch is held vertically downwards separated by 15 mm above a plate which is travelling horizontally at the constant speed of 35 cm/min.

The arc and the material transfer phenomena are observed using the method of high-speed photography with HYCOMB 16 mm high-speed cine-camera. Simultaneously the arc current and total voltage drop between the top of contact tip and the bottom of base metal are measured by the use of an electromagnetic oscillograph with the maximum frequency-responce of 2 kHz.

Oxygen and nitrogen contents in the weld metal are chemically analyzed by LECO apparatus.

3. Unstable Phenomena

Initially weld beads were laid to observe the metal transfer characteristics under the following condition,

Polarity	DCRP,
Welding Speed	35 cm/min,
Shielding Gas	Pure Argon.

In **Fig. 1**, the variation of metal transfer mode related to the change in output voltage and current of the power source is shown. The figured pattern on the classification of the characteristics on metal transfer is fundamentally depended on the relation between the feeding rate of the wire and the output current. Since the feeding rate of the usual automatic welding machine is that of the constant wire feed system, the qualitatively similar configuration can be obtain with any conventional machine.

At low currents, there is globular transfer and as the current increases a transition occurs to spray transfer. In the globular transfer region, the arc is unstable, shown in **Photo. 1**, and traces of movement of arc roots become remarkably broad in comparison with the width of weld bead.

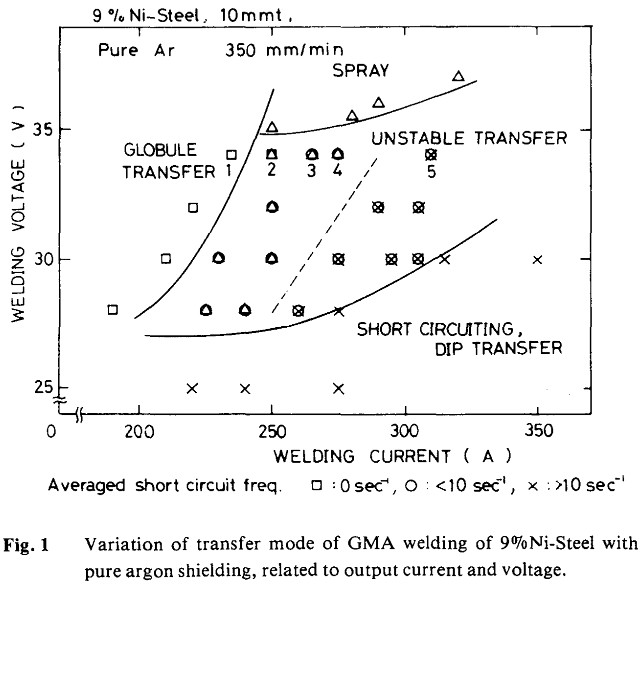

Fig. 1 Variation of transfer mode of GMA welding of 9%Ni-Steel with pure argon shielding, related to output current and voltage.

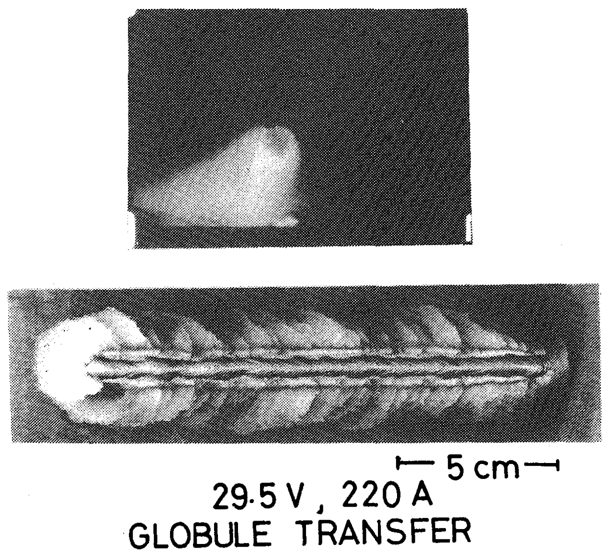

Photo. 1 Arc configuration in globular transfer mode in lower current and typical bead appearance.

In the spray transfer region, the length of arc is comparatively long ($\geq$ 7 mm) and the transfer mode is not easily to be changed but the cathode spots of arc have random movements over the extensive area on the plate surface. When some of these cathode spots concentrate, a jet of metal vapor is formed at the point and the arc column and material transfer are distorted by the jet force, therefore, the bead appearance is resulted in snaked one shown in **Photo. 2.**

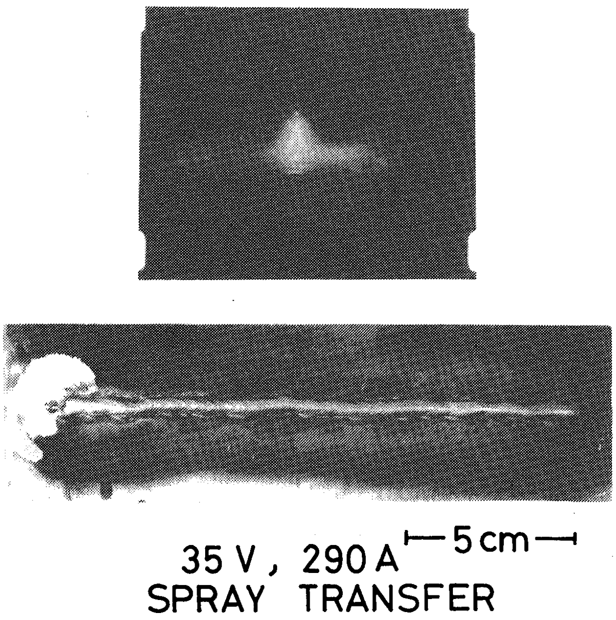

Photo. 2 Arc configuration in spray transfer mode and typical bead appearance.

A photographic sequence showing the fluctuation of arc column associated with the formation and development of vapor jet by the concentration of cathode spots is displayed in **Photo. 3.** The time-interval between frames selected for illustration is 1/90 sec. An example of time-variation of current and voltage of arc is displayed in **Fig. 2.** When a creation of the concentrated spots occurs, appreciable and rapid changes in the waveforms of current and voltage appear.

At lower voltage the welding process is of short-circuiting arc dip transfer mode. A bead appearance and a time-variation of current and voltage are illustrated in **Fig. 3.** As described above, the defect which is due to the lack of fusion is sometimes encountered under this condition with high-nickel allow wire.

The central part of **Fig. 1** is the transition one between the region of spray transfer mode and that of short-circuiting arc dip transfer mode, and the material transfer become unstable, furthermore periodic change between the two modes occurs. A typical time-development of current and voltage of the arc is illustrated in **Fig. 4.** In the period between the spray transfer mode and the dip transfer one, a large number of small and sharp spikes appear in the voltage wave-form. Photographs of arc in this phase manifest that the end of wire electrode become considerably tapered and the neck is extended into a long filament terminating in a spray of fine droplets. Sometimes this fine string of wire metal is short-circuited and instantaneously exploded with the cosequence that sputtering or/and exploding of molten metal take place.

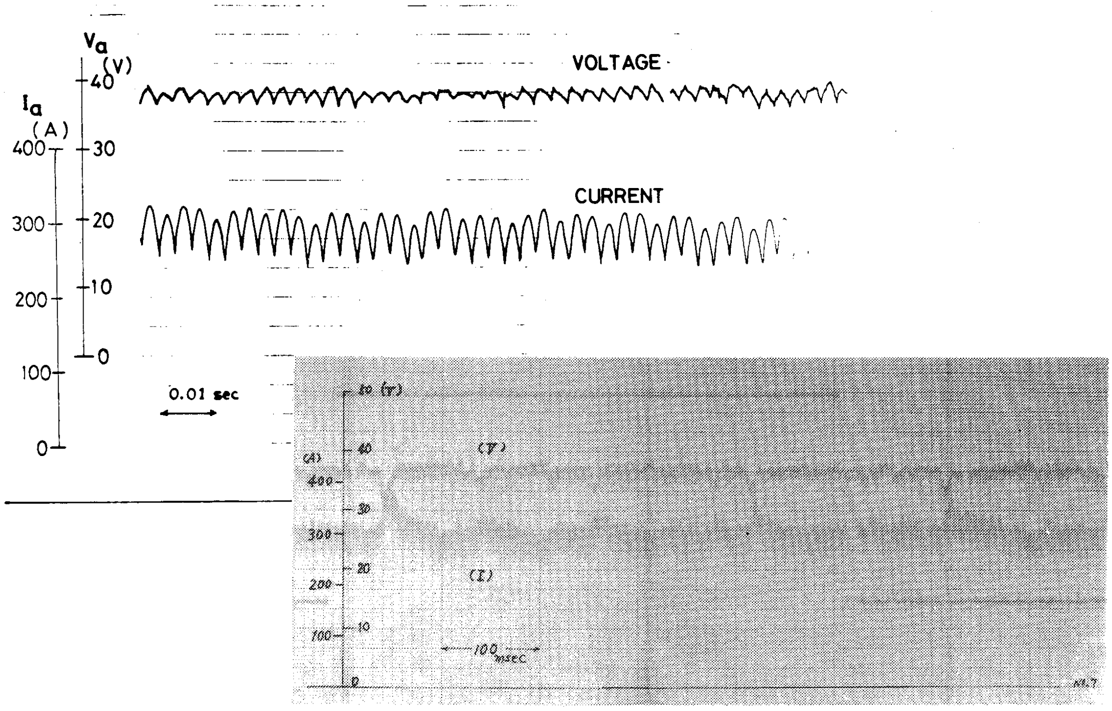

Fig. 2 Typical time-variation of current and voltage of arc operated in spray transfer mode. Chart speed of upper traces is 10 times higher than that of the lower.

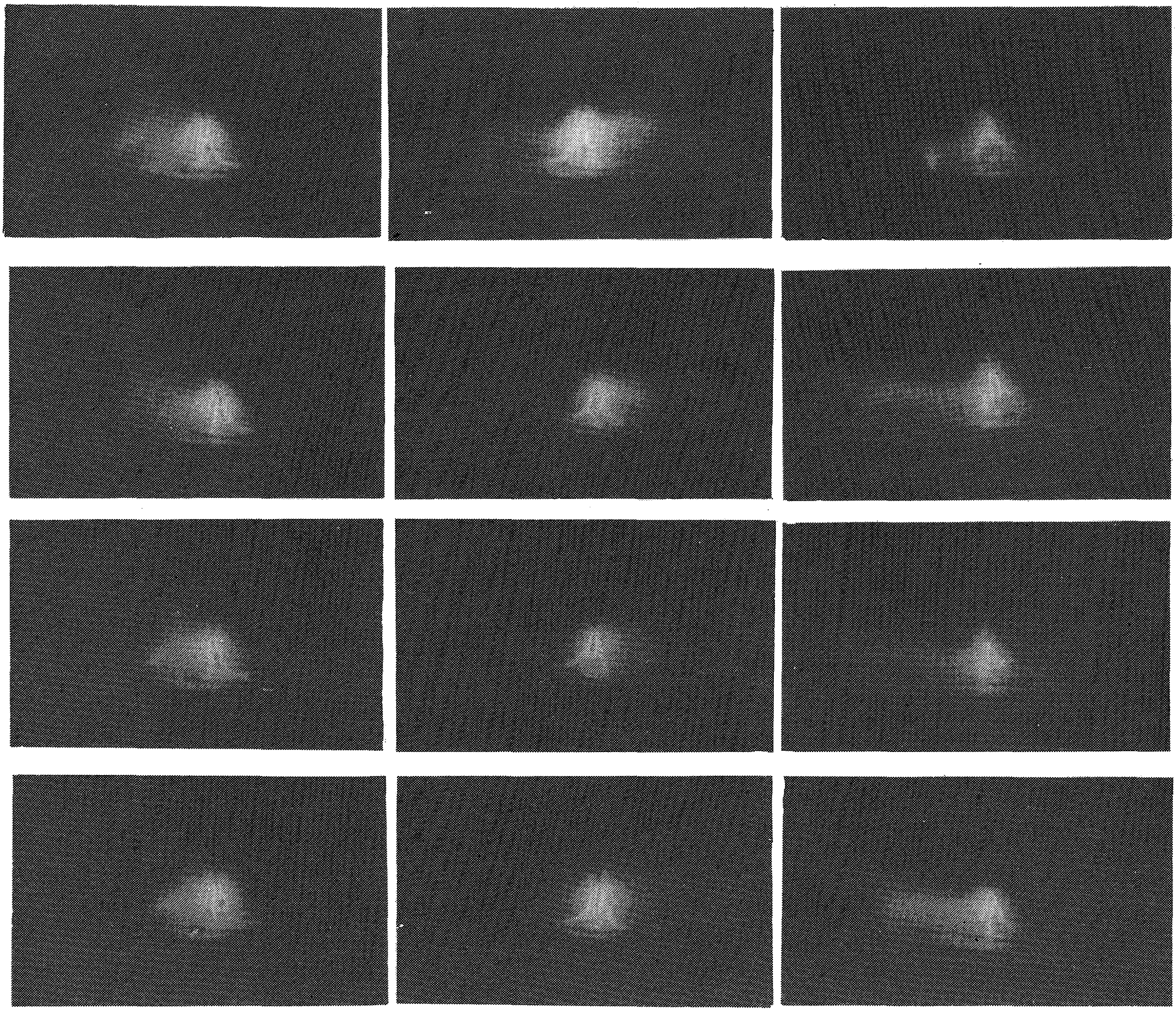

Photo. 3 Fluctuations of arc column associated with erratic behavior of arc roots. Arc configuration changes sequentially from that of the top-left view to downward one with time-interval between two frames of 1/90 sec.

The spike can be regarded as the induced voltage of circuit at the instance of the break of contact.[3, 4] Due to the shortness of arc length in the spray phase (< 5 mm), the width of "cathode area" is narrower in some degree than that in the spray transfer mode at higher voltage, but the width and the depth of weld bead have irregularities corresponding to the change in transfer mode. Bead appearances and arc voltage waveforms under the numbered conditions in **Fig. 1** are displayed in **Fig. 5** and the oxygen and nitrogen contents in those weld metals are illustrated in **Table 2.** As the current increases, the value of which is measured in the phase of spray transfer mode, the averaged short-circuiting frequency and the content of oxygen tend to increase. Since the content of nitrogen has no appreciable change with the increase of current, the distortion of argon gas shroud due to the explosion of short-circuited metal can be neglected. Therefore, the increase of oxygen content in weld metal may be attributable to the multiplication of deposited metal and insufficiency of dilution in spite of the increase of power loss.

4. Effect of oxygen on the stabilization of arc and transfer

A remarkably stable arc and spray transfer can be observe with suitable adding of O_2 or CO_2 gas to argon shielding gas, shown in **Photo. 4.** There are no visible cathode spots as such, but it is thought that there are a large number of coexisting individual spots spread dif-

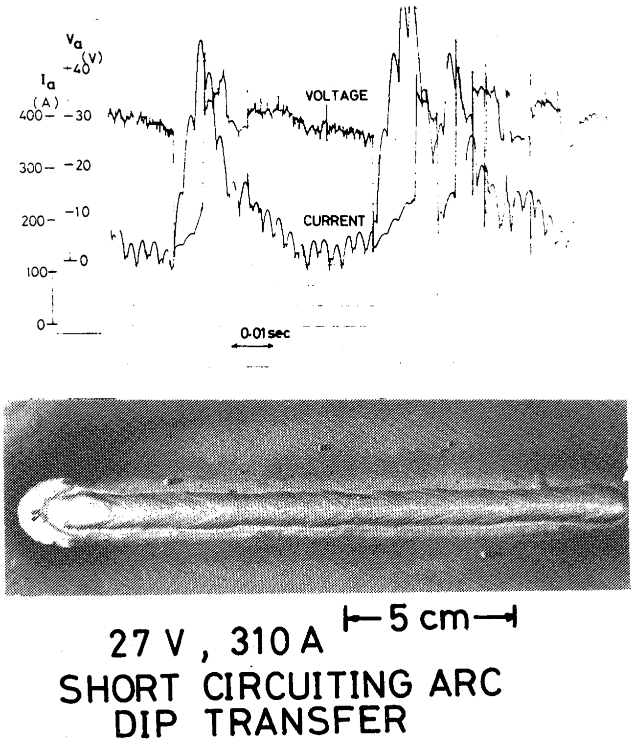

Fig. 3 Time-variation of current and voltage of arc operated in short-circuiting arc dip transfer mode and bead appearance.

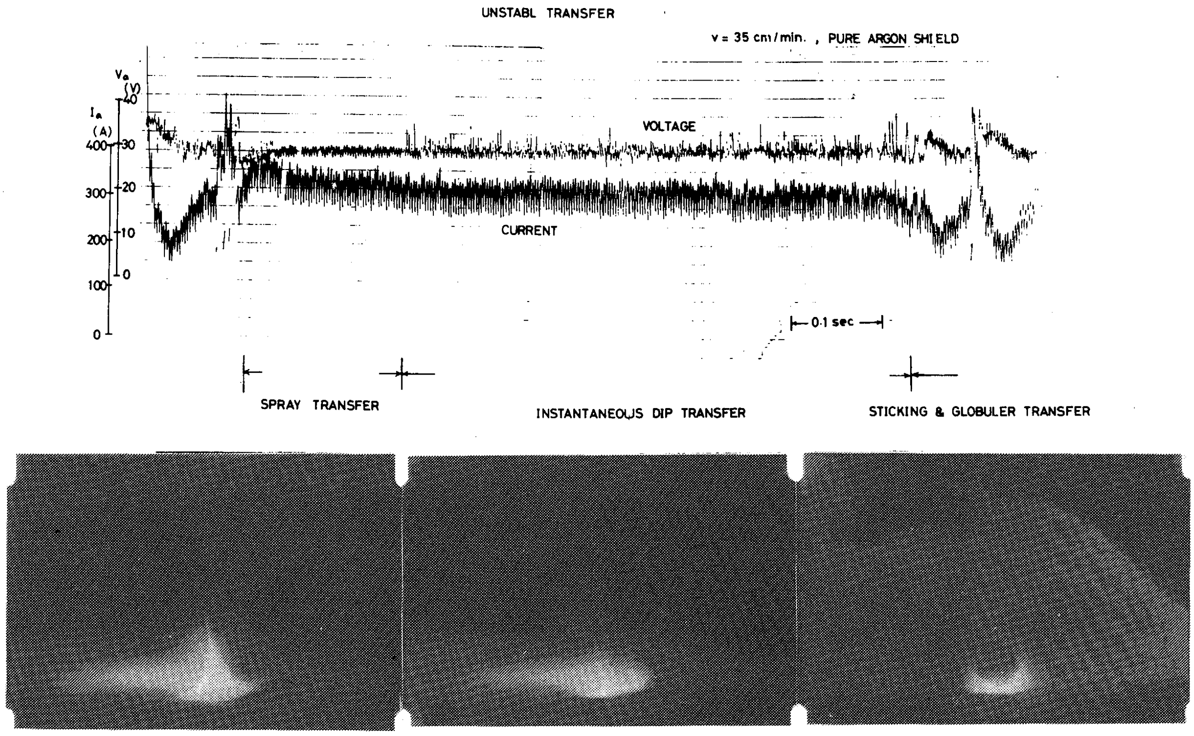

Fig. 4 Time-development of transfer mode showing periodic change between short-circuiting arc dip transfer mode and spray transfer mode.

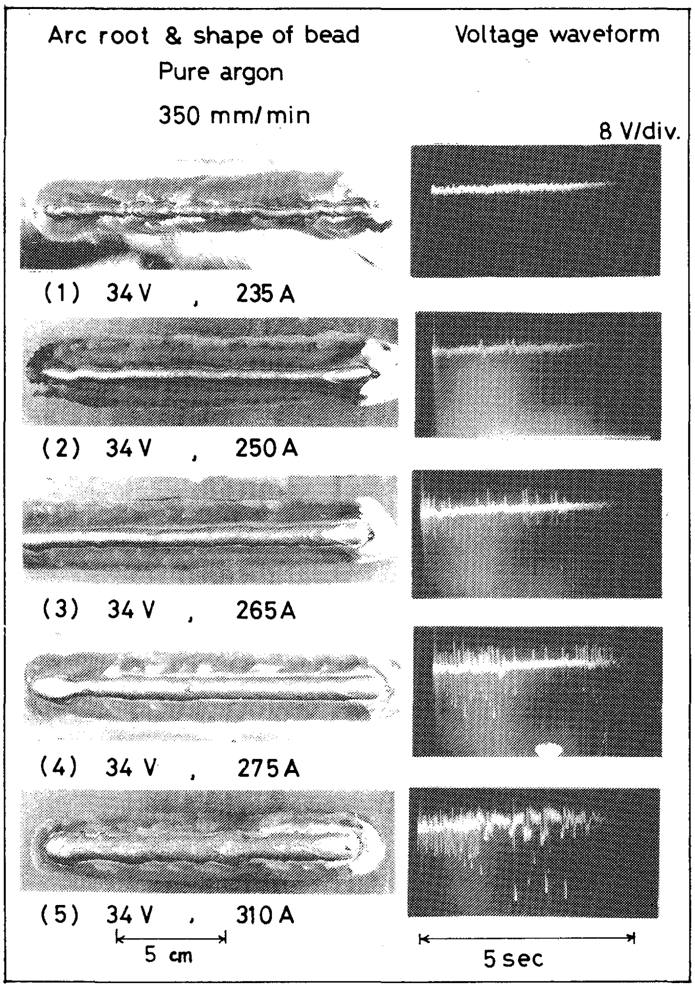

Fig. 5 Appearances of traces of arc roots, shapes of bead and voltage waveforms in cases of numbered condition in Fig. 1.

Table 2 Oxygen and nitrogen contents in weld metals under the numbered conditions corresponding to the numbered plots in Fig. 1.

WELDING CONDITION	SPEED:350 MM/MIN.,PURE ARGON				
VOLTAGE:34V	1	2	3	4	5
CURRENT(A)	235	250	264	275	310
TRANSFER MODE	GROBULE	UNSTABLE TRANSFER			
SHORT CIRCUIT FREQ. (SEC^{-1})	□ 0	△ 0~2	△ 2~10	△ 2~10	⊠ ≥ 10
OXYGEN CONTENT IN WELD METAL(PPM)	24	31	34	49	55
NITROGEN CONTENT IN WELD METAL(PPM)	48	47	55	40	42

fusively over the "cathode area".

The changes in bead appearance and traces of "cathode area" in cases of variable content of O_2 or CO_2 in shielding gas mixture are displayed in **Fig. 6** and **7.** Minimum content of O_2 or CO_2 required to stabilize the arc roots and material transfer is respectively 0.3 ~ 0.5% or 0.7 ~ 1.0% under the condition

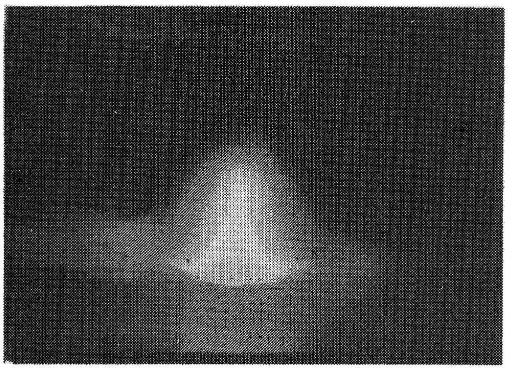

Photo. 4 A stable arc and roots with argon +0.4% O_2 shielding gas.

represented in the figure, which increased slightly as the welding speed was increased from 10 cm/min to 50 cm/min.

With those mixed gas shielding, the long and fine string of wire metal formed at the end of the protruded and tapered electrode is disappeared. It can be interpreted as the high rate of energy consumption in the central part of the arc column by the use of dissociable gas mixture and the stabilization of arc configuration associated with continuous supply of sufficient oxygen to form the oxide cathode roots, prevent the arc from "climbing up" the electrode.

The arc is run in pure argon shroud with the cathode of the plate which are prior oxidized by holding at temperature around 400°C in air for variable durations. The cathode roots are stably located in the vicinity and just ahead of the advancing weld pool only with the plate whose heat-treatment time is above 3 hours. The thickness of oxide layer of the plate heated for 3 hours is approximately 0.5 μm and oxygen con-

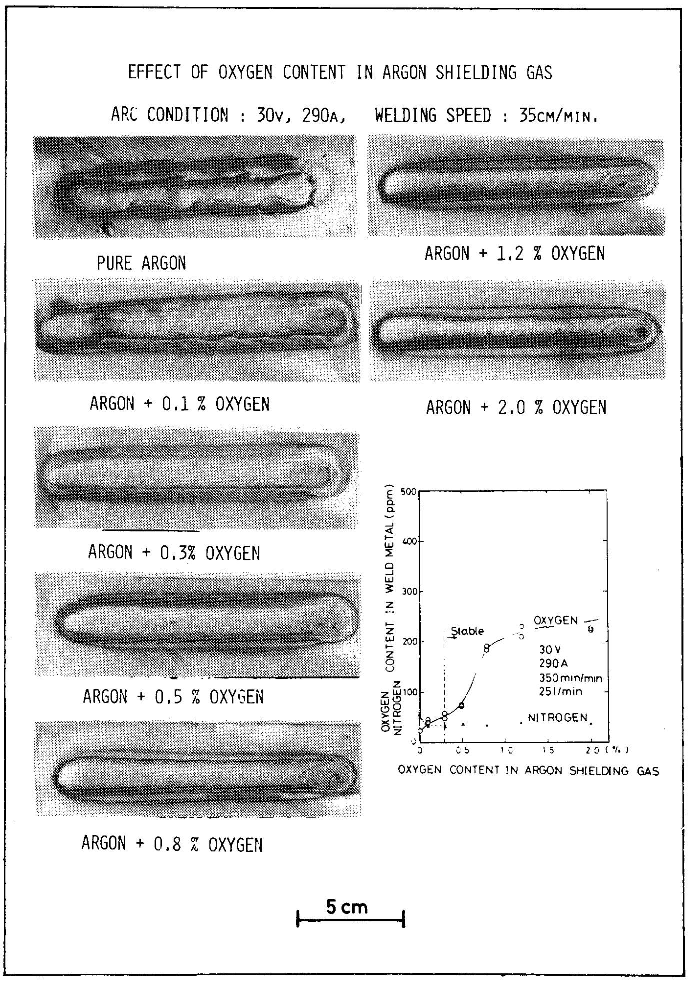

Fig. 6 Appearances of beads and traces of "cathode area" in cases of various O_2 contents in argon shielding gas.

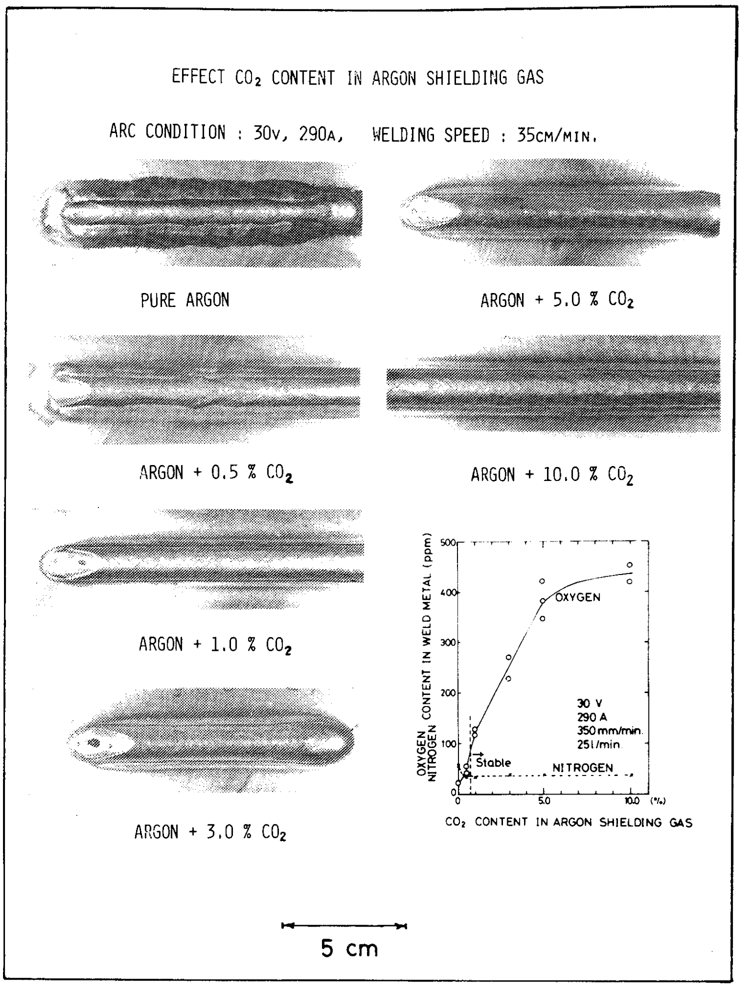

Fig.7 Appearances of beads and traces of "cathode area" in cases of various CO_2 contents in argon shielding gas.

tent in its weld metal is about 60 ppm **(Table 3)**, this level of oxygen is significantly low.

It is suggested from these results, the successful operation of arc welding depends substantially on the behavior of arc roots. it is shown that using the gas mixture containing O_2 or CO_2, or pre-oxidizing the plate surface, the stable welding which can be suppress the oxygen content in weld metal to the value below 100 ppm can be accomplished.

Table 3 Chemically analyzed contents of oxygen and nitrogen in weld metals with plates oxidized by pre-heating at 400°C for various durations.

Heat treatment time (HOUR) 400°C in air	0	1	3	5	8	15
Oxygen content in weld metal (PPM)	39	52	62	91	95	110
Nitrogen content in weld metal (PPM)	49	41	36	32	34	35

Welding condition: 30V, 290A, 350mm/min., Pure argon 25l/min..

5. Conclusions

(1) Using a conventional welding system, two types of unstable phenomena are observed in 9%Ni-Steel GMA welding with a similarly composed filler wire. One is the fluctuation of arc column associated with the erratic behavior of arc roots in spray transfer mode, the other is alternate occurence of material transfer mode between the spray transfer and dip transfer.

(2) These unstable phenomena can be stabilized by the adding O_2 or CO_2 gas to argon shielding gas, or by the forming a oxidized surface on the plate. The minimum content of O_2 or CO_2 in shielding gas required to stabilize the arc is $0.3 \sim 0.5\%$ or $0.7 \sim 1.0\%$, respectively, and the minimum thickness of oxidized layer necessary for stable localization of arc roots is about $0.5\ \mu m$.

It should be noted that under the condition described above the successful operation of conventional arc welding system can be accomplished and the content of oxygen in weld metal is significantly low, which is below 100 ppm. It should be suitable to ensure the resulting mechanical properties of the weld metal.

Acknowledgement

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