Long arc stabilities with various arc gas flow rates

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Abstract. A new arc torch for use in magnetically driven arc device was developed with a commercially available TIG welding arc torch. The torch has a water-cooling system to the torch nozzle and has a nozzle nut to supply a swirling-free plasma gas flow. Its endurance against arc thermal load is examined. Features of its generated arc are investigated.

1. Introduction

Electric arcs, which are widely used as high-intensity heat sources in various industry activities, have power output that is easily controllable by adjustment of the arc current. Among different modes of arc operation, a transferred arc is often used in many material processes such as welding, cutting, melting, and refining metals because of its high-efficiency heat transfer. Thermal and electromagnetic pinch effects act on the arc, which concentrates the heat flow into a small area. This property is desirable to obtain high temperatures in a narrow zone of the material, but it is not convenient for heating wide areas of materials.

Several trials were conducted to expand the arc heating area [1−3]. The authors obtained a wide heat source by imposing an alternating magnetic field perpendicularly to a transferred arc [4−6]. The arc is driven by an electromagnetic force induced from the interaction between the magnetic field and arc current, which is flowing into the arc column. Therefore, the alternating magnetic field enables the arc to oscillate. A high-speed oscillating arc can be regarded as an expanded heat source with width of the oscillation amplitude. In addition to conventional arc characteristics, a magnetically driven arc presents the following benefits:

(1) The heat-source width, the width is namely the width of the oscillation amplitude of the arc, can be varied easily by adjusting the imposed magnetic field.

(2) The heat flux density distribution can be controlled by varying the waveform of the imposed magnetic field.

For example, if the waveform of the magnetic field is rectangular, then the heat flow is concentrated at both ends of the oscillation.

In a recent investigation, a magnetically driven arc technology was applied to steel plate heat treatment [7]. The authors have developed a novel heat treatment system for steel product using a magnetically driven arc. This equipment is able to raise the steel plate heat treated area hardness up to 2−3 times that of a non-heat-treated surface.

With this equipment, however, swirling gas flow was used to stabilize the arc plasma, which makes the arc oscillation surface inclined because the movement of a magnetically driven arc is twisted by Magnus force. Therefore, the heat treatment surface edge is also inclined, which causes an
error in the heat treatment and which is inconvenient for the application [8]. In addition to this swirling
gas problem, the optimum gas flow rate for the using torch nozzle diameter to treat the surface has
never been reported in the literature. This misunderstanding often engenders a cratered surface on
heat- treated steel plate.

In the present study, a novel plasma torch is developed for heat treatment, using a low-cost
(commercial) arc torch with a swirling-free nozzle. Furthermore, characteristics of the arc generated
with this torch are investigated. The optimum arc gas flow rates for the new nozzle for application for
heat treatment are determined.

2. Development of a swirling-free gas flow torch
A swirling-free arc torch for a magnetically driven arc device was developed using a commercially
available torch for TIG welding. Figure 1 shows the torch (WP-18SP; by La Mer Co. Ltd.).

![Figure 1. Photograph of a commercially available TIG welding torch used in this study.](image)

This torch has an alumina nozzle that gives no-swirling flow to plasma gas. However, when we used it
for a preliminary study of a magnetically driven arc, the alumina nozzle was melted because a strong
thermal energy flows from the arc plasma, as shown in figure 2.

![Figure 2. Photograph of the melted alumina nozzle.](image)

To avoid melting down of the nozzle, a cooling system made of copper was equipped on the torch as
shown in figure 3(a).

![Figure 3. Photograph of a torch nozzle cooling system: (a) is the overall picture of nozzle cooling
system, and (b) is the exchangeable nozzle nut.](image)

Figure 3(b) shows a copper nozzle nut included in the new cooling system. The nozzle nut can be
exchanged. Therefore the arc diameter is variable. In this development, four nozzles are prepared with
diameters of 3.2 mm, 4.0 mm, 5.0 mm, and 6.0 mm.

3. Experimental method
Figure 4 presents an experimental arrangement for long straight-through arc generation.
A DC power supply, which outputs constant current, is connected to plasma torch and anode. The plasma forming gas is argon, which is fed to the plasma torch. A transferred arc, which is straight-through form, is generated between the plasma torch and the anode. The anode, a copper plate of 5 mm thickness, is cooled by water sprayed onto the lower side of the anode. The arc voltage is measured using a voltage meter connected in parallel to the power supply. Therefore, the obtained value contains some errors, although it is presumably negligible compared to the actual arc voltage. The obtained data flow through an A/D converter and are continuously recorded on the linked PC. The A/D converter outputs the analysis data length of 0.8 s because the memory can store only 2048 samples though the sampling rate is 2560 Hz. Photographs of the arc profile are taken using a camera as shown in figure 4.

Table 1 presents the experimental conditions.

| Parameters          | Symbols | Values     |
|---------------------|---------|------------|
| Arc current         | $I_a$   | 60 A       |
| Gas flow rate       | $Q_{Ar}$| 3–12 NL/min|
| Electrodes gap      | $L$     | 50 mm      |
| Nozzle diameter     | $d$     | 5.0 mm     |

4. Experimental results and discussion

4.1. Arc profile transitions with various arc gas flow rates

Figure 5 presents photographs of arc profile variations as the arc gas flow rate is increased from 3 NL/min to 12 NL/min.

![Figure 5. Photographs of the arc profiles in various arc gas flow rates. The camera exposure time is 1/4000 s.](image)
As might be apparent from figures 5(a) and 5(b), the arc column is almost straight through when the arc gas flow rate is small. However, as the gas flow rate increases, it turns to the right and the left. The turn length also increases as shown in (c) and (d). We refer to the arc profiles of (a) and (b) as the “Laminar flow arc”, and to those of (c) and (d) as “Turbulent flow arc”. Figure 5 also shows that the total arc column length increases as the gas flow rate increases. Therefore, it can be expected that the arc voltage increases corresponding to the arc column extension. The average of the measured voltage values over 0.8 s is calculated, which is considered DC component of the arc voltage here. Figure 6 presents variations of the DC component in the arc voltage for various arc gas flow rates. The values are almost constant between 3 NL/min and 5 NL/min, which agrees with the arc profile in straight form depicted in figure 5(a). However, the arc voltage increases linearly with the gas flow rate of more than 5 NL/min, which is explainable by the reasons presented above.

Figure 6. Variations of DC component in the arc voltage for various arc gas flow rates. The error bars indicate arc voltage fluctuations.

4.2. Measurement of fluctuation in arc voltage with various arc gas flow rates
Figure 7 shows temporal variation of arc voltage fluctuation for various arc gas flow rates corresponding to those of figure 5.
In figures 7(a) and 7(b), which are the “Laminar flow arc”, the fluctuation in arc voltage is within $\pm 10 \text{ V}$. In contrast, the fluctuation in arc voltage is over $\pm 10 \text{ V}$ in (c) and (d), which are “Turbulent flow arc”. This result implies that the fluctuation in arc voltage results from the rapid profile change of the arc column. In the case of the “Turbulent flow arc”, extensions and contractions of the arc column possibly occur in an extremely short time. The degree of such changes increases with the arc gas flow rate.

Then, we calculate the root-mean-square (RMS) value of the fluctuation in arc voltage for each of the arc gas flow rates by the following equation:

$$V_{RMS} = \sqrt{\frac{\sum (V_{\text{fluctuation}})^2}{N}}.$$ 

Here, $V_{\text{fluctuation}}$ is the fluctuation in arc voltage. Figure 8 presents the variations of the RMS values of arc voltage fluctuation for various arc gas flow rates.

![Figure 7](image1.png) ![Figure 8](image2.png)
In figure 8, the closed circles denote the calculated values of fluctuation in arc voltage from experimentally obtained results. The two solid lines and a broken line indicate inclination of their variation. When the gas flow rate is that for “Laminar flow arc”, the RMS fluctuation value is about 0.5 V and is not so changed. However, when the gas flow rate is that for “Turbulent flow arc”, the RMS fluctuation value slightly increases from 7.8 V to 9.3 V. The most interesting feature in this result is that the RMS fluctuation value increases drastically between 6 NL/min and 7 NL/min. More detailed knowledge about this steep increment is necessary. We intend to study that subject in our future work.

5. Conclusions
A swirling-free plasma torch with a water-cooling system for the nozzle part for a magnetically driven arc device was developed. Then the arc characteristics were investigated. A long stable arc was generated for various arc gas flow rates. The following are the remarkable results obtained from the gas flow rate changing experiment.

1. The torch nozzle was confirmed as undamaged, although the arc column is not oscillated yet.
2. The arc profile changes drastically from a laminar type to a turbulent one as the arc gas flow rate increases.
3. The DC components of arc voltage change linearly with the arc gas flow rates.
4. Fluctuation in arc voltage also steeply changes with the arc gas flow rates, which corresponds to the arc profile change.

These results suggest that the optimum gas flow rate for heat treatment application is less than 6 NL/min.

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