Understanding and Suppression of Magnetic Arc Blow in Plasma Arc Cutting Torch

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Abstract: To predict and prevent the occurrence of magnetic arc blow, we examined the relationship between operating conditions and occurrence of the abnormal discharges called "double arc" when an external magnetic field was applied to the plasma jet with and without a magnetic shielding cap on the torch. The threshold magnetic flux density for the double arc occurrence B_{th} has a strong dependence on the arc current and main gas flow rate. When the magnetic shield cap was installed at the torch, the double arc was suppressed.

Keywords: Magnetic arc blow, Double arc, Plasma arc cutting, Magnetic shield.

1. Introduction

Plasma arc cutting is widely used in metal cutting because of its advantage of high speed cutting. However, when a magnetized steel plank is cut, the electromagnetic force induced by magnetic flux leakage in the cutting edge deflects the arc plasma jet. Deflected plasma jet roughens the cutting surface and damages the nozzle as the arc cutting processes proceed to the side end. This phenomenon is called "Magnetic Arc Blow".

It's not easy to prevent steel plank from magnetizing because steel plank is magnetized for a variety of reasons, such as processing and heat treatment during manufacture or magnetization during transport by lifting magnet. In addition, it takes time and money to demagnetize a large steel plank that has several square meters which is often used in plasma arc cutting. For above reasons, suppression of magnetic arc blow is required by means of developing process design of the plasma torch.

In arc welding, magnetic arc blow is a serious problem and it has been studied for a long time [1], [2]. However, in plasma arc cutting, magnetic arc blow has not been recognized as an important task because the plasma jet blowing out from the nozzle as high temperature and high speed gas stream is less affected of the external magnetic field. Only symptomatic treatment, such as changing the operating conditions in the field is shown. So far, little physical details have emerged on the magnetic arc blow in plasma arc cutting. Since the increased occurrence of the phenomenon is expected by the development and use of high-tensile steel that is easy to magnetization, understanding of the magnetic arc blow and establishment of suppression technique are strongly required.

In this work, we examined the relationship among operating conditions, such as arc current, gas flow rate and so on, and occurrence of the abnormal discharges when an external magnetic field is applied to the plasma jet. In addition, an attempt was made to suppress the abnormal discharges by magnetic shielding on the torch.

2. Experimental set-up

2.1. Plasma arc cutting system

For experimental tests a Komatsu Industries plasma cutting system was used. This system is composed of a plasma source, cooling unit, gases unit, high frequency unit, and a plasma torch. Power is an inverter type DC constant current source with maximum current 150 A. The plasma torch and anodes are shown in **Fig.1**. A pair of water-cooled anodes made of cupper was used in order to simulate a cutting plank. Cathode is composed of Cu-holder and Hf-insert with a diameter of 1.6 mm working in association with a nozzle with a 1.3 mm diameter orifice. Main gas and assist gas are supplied from the gases unit to the plasma torch. Main gas and assist gas are O_2 and N_2, respectively. High frequency unit applies a high frequency high voltage between the cathode and the nozzle to ignite a plasma arc. Main gas is ionized and ejected from the nozzle orifice as a plasma jet with high temperature and pressure. Assist gas is ejected from the gap between the nozzle and the shield cap to stabilize the arc, protect the nozzle parts, and improve the quality of the cutting surface.

2.2. Applying external magnetic field to the plasma jet

In order to generate the magnetic arc blow, the magnetic field generated by DC electromagnets Tohodenki TRM89 was applied to the plasma jet. **Fig.2** shows arrangement of a pair of electromagnets and a plasma torch. The orientation of applied magnetic field is

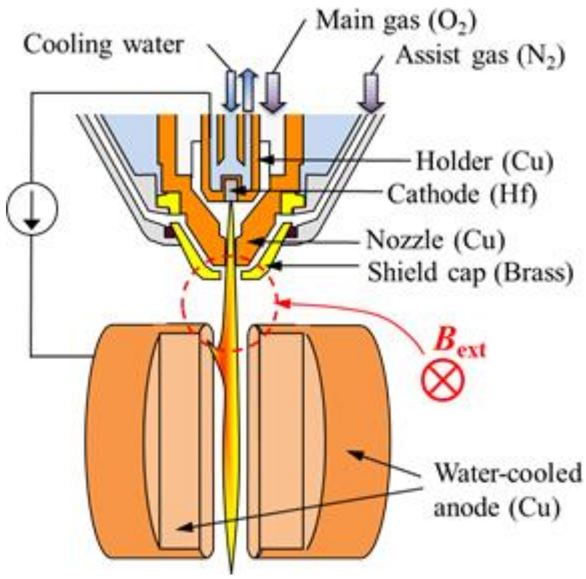

Fig.1. Plasma arc cutting torch and water-cooled anodes.

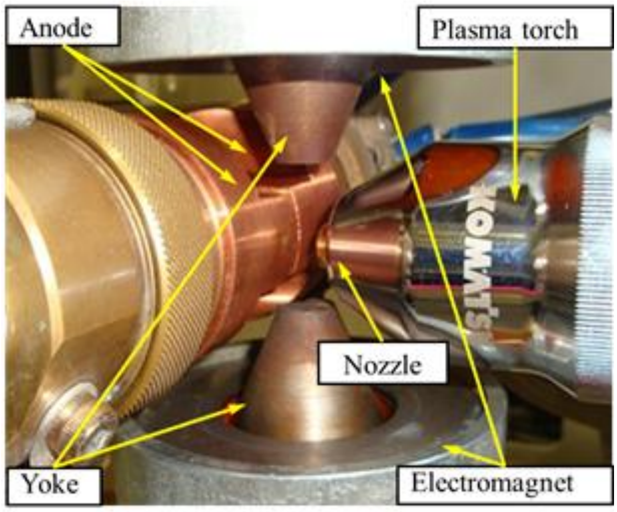

Fig.2. Arrangement of a pair of electromagnets.

from top to bottom on the picture and perpendicular to the plasma jet. Tapered steel cores were used to concentrate magnetic field on the plasma jet. There is a peak of magnetic flux density near the core on the torch axis. This peak value of the magnetic field is defined as B_{ext} in the present study. B_{ext} can be controlled by DC current up to 140 mT.

2.3. Double arc and Threshold magnetic flux density B_{th}

Plasma jet is deflected to the wall of the nozzle orifice by the Lorentz force. When it contacts the wall of the nozzle electrically, secondary abnormal discharges between the cathode and the anode are formed through the nozzle in addition to the normal arc current path through the nozzle orifice. It is called “Double Arc”. We focused on the double arc in particular, and observed with a monochrome high-speed video camera. A NAC Memrecam GX-8 camera was used, with a maximum acquisition speed of 600,000 fps. In addition, the threshold magnetic flux density for the double arc occurrence B_{th} was measured on the operating conditions such as arc current, main gas flow rate, assist gas flow rate, and nozzle orifice diameter.

2.4. Magnetized steel cutting

Steel planks magnetized by attaching neodymium magnets of about 500 mT surface magnetic flux density to both ends of the planks were cut in plasma cutting to generate the double arc deliberately. **Fig.3** shows an experimental cutting plank with magnets. The dimensions of the plank were 16 mm in thickness by 200 mm in width and, 100 mm in length. Double arc occurrences were observed with a color high-speed camera Keyence VW-6000. The quality of cutting surface was evaluated after cutting. Arc current during cutting phase was 150 A, and the nozzle orifice diameter and torch height from the plank were 1.6 mm and 2.5 mm, respectively.

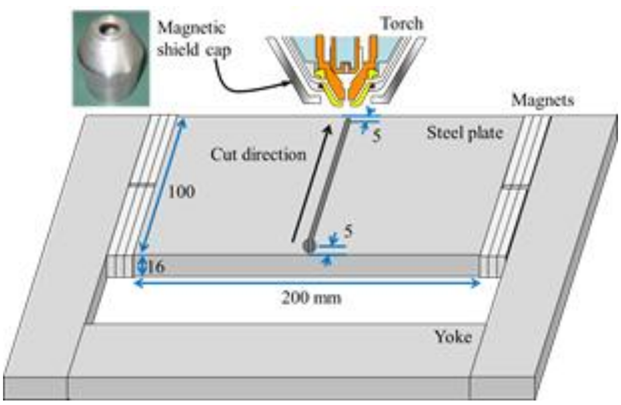

Fig.3. Schematic diagram of the experimental cutting plate with magnets.

2.5. Suppression of Double arc with magnetic shielding

Threshold magnetic flux density B_{th} can be shifted by changing operating conditions. In addition, we tried a method of less susceptible to magnetic field with magnetic shielding to the plasma torch. The magnetic shield cap used in this study is shown in **Fig.3**. Threshold magnetic flux density B_{th} was measured with a magnetic shield cap being attached. Cutting tests with magnetic shield cap were also performed on the plank.

3. Results

3.1. Arc behavior and voltage fluctuation in the external magnetic field.

Fig.4 shows selected high-speed imaging frames during double arc with operating conditions of 135A arc current, 10 L/min main gas flow rate, and 20 L/min assist gas flow rate. Since the magnetic field was applied in a direction toward the back of the paper, Lorentz force acted toward the left from the right on the paper. The double arc occurred when the external magnetic field was increased to 20 mT. In the first image, the plasma jet was being blown out from the nozzle and passing between two anodes. In the second image, the other arc discharge between the nozzle and an anode is shown in addition to the plasma jet forming between the anodes. This abnormal discharge was a consequence of deflected arc coming into contact with the nozzle orifice.

The fluctuations of arc voltage and arc current are shown at the bottom of **Fig.4**. The double arc was occurred at 4.1 ms, 5.0 ms, and 6.0 ms. The arc voltage fell at the same time of the occurrence of the double arc because resistance between electrodes was decreased by forming of other current paths.

Fig.5 shows a schematic diagram of a double arc occurrence in the nozzle. Arc plasma is shrinked in the nozzle orifice and blown out. In the normal discharge, due to the part of main gas that has not ionized and flows between the arc plasma and the nozzle orifice inner walls as cold gas, arc plasma and the nozzle are isolated electrically and thermally from each other, and the arc plasma is being stabilized. Hence, it is assumed that with the Lorentz force with a small external magnetic field of several mT, arc plasma is not disturbed. Arc plasma will be brought into contact with the nozzle when the external magnetic field reaches to the threshold value of 10 mT or more.

3.2. Threshold magnetic flux density of Double arc

The threshold magnetic flux density for the double arc occurrence B_{th} has a strong dependence on the arc current and main gas flow rate as shown in **Fig.6**. The solid line and the dotted line indicate 1.3 mm nozzle diameter and 1.6 mm, respectively. With increasing arc current, B_{th} decreases because the Lorentz force $j \times B_{ext}$ increases and arc plasma is more deflected. B_{th} also decreases with decreasing main gas flow rate because electrical insulation between the plasma jet and the nozzle become less effective. In addition, if the nozzle diameter is small, the deflected arc plasma becomes likely to contact with the nozzle wall. For the above reasons, double arc is likely to occur.

From the experimental data, B_{th} [mT] is empirically given by the following equation,

(1)

where Q [L/min] is main gas flow rate, I [A] is arc current. B_{th} is approximately proportional to Q and inversely proportional to I.

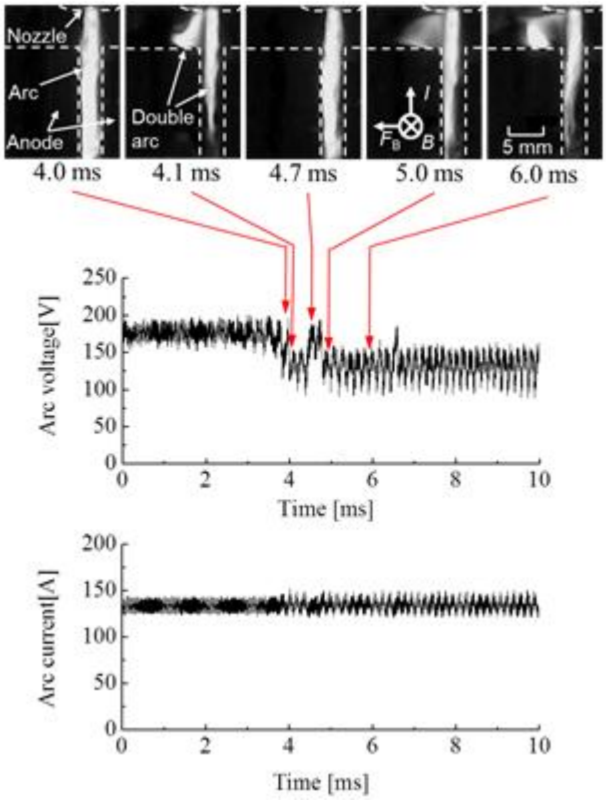

Fig.4. Arc voltage and arc current during double arc

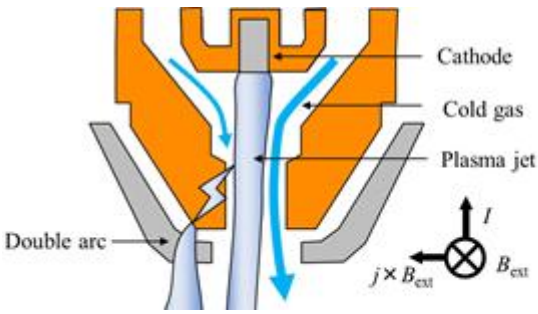

Fig.5. Arc plasma behavior in the nozzle of arc plasma torch.

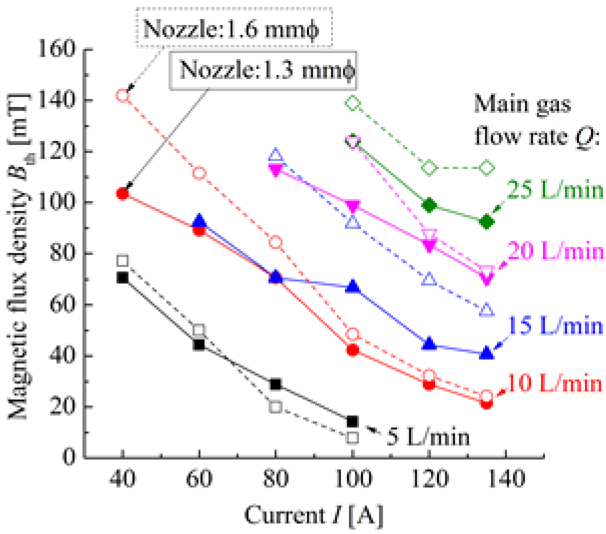

Fig.6. Arc current dependence of B_{th}, varying the main gas flow rate Q from 5 to 25 L/min.

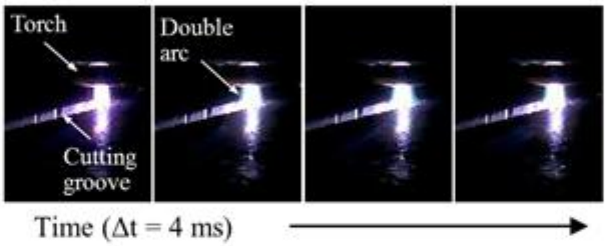

Fig.7. Frame by frame of images of double arc phenomena when the magnetized steel plank was cut.

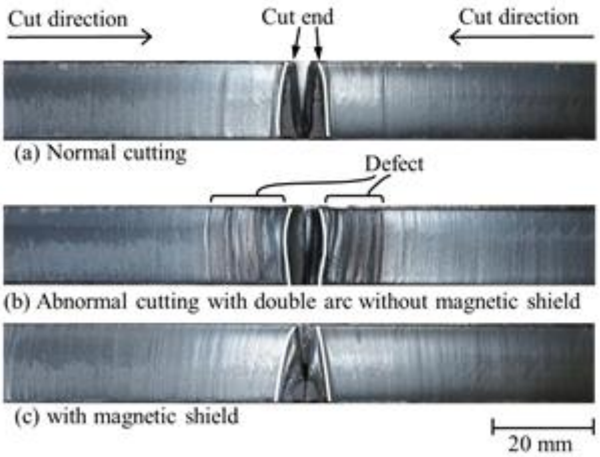

Fig.8. State of the cut surface in plasma arc cutting.
(Main gas flow rate 13 L/min, magnetic intensity 30 mT)

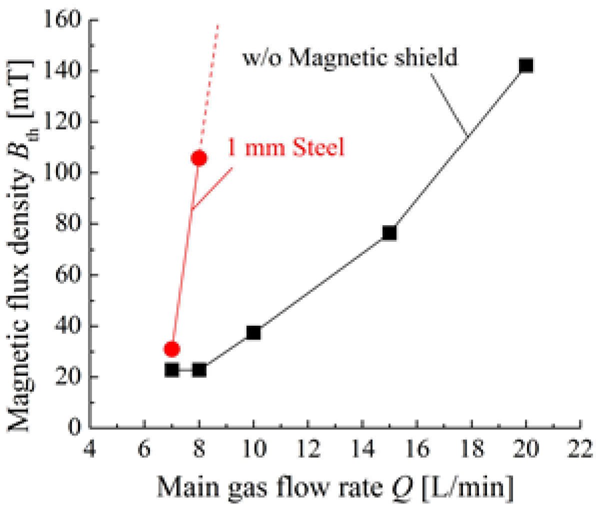

Fig.9. B_{th} with or without magnetic shield cap with arc current of 135 A.

3.3. Double arc in the magnetized steel cutting

The double arc occurrence during cutting magnetized plank is shown in **Fig.7**. Main gas flow rate and Assist gas flow rate were 13 L/min, 25 L/min, respectively and arc current was 150 A. The leakage magnetic field at the tip of the torch was maximum 30 mT. In the images of the second and subsequent, arc plasma was disturbed and the double arc was generated. The plank was separated after plasma cutting and the cutting surface was observed as shown in **Fig.8**. The left side of the image is the left piece of the plank and the right side of the image is the right piece of the plank. Compared with the cross section with normal cutting (a), the cross section with double arc (b) has poor cutting quality near the end of the plank. When the cutting point approaches the end of the plank, the magnetic field in the plank is concentrated in the uncut part, and leakage magnetic field near the torch increases.

3.4. Magnetic shielding on the torch

Fig.9 shows threshold magnetic flux density B_{th} with or without magnetic shield cap of 1 mm thickness. B_{th} with magnetic shield cap was increased significantly due to the magnetic field in the nozzle was decreased. When magnetic shield caps of thickness 3 mm or 5 mm were used, no double arc was occurred under same operating conditions.

Cutting surface with a 5 mm thickness magnetic shield cap is shown in **Fig.8 (c)**. Cutting surface is smooth due to the absence of the double arc.

4. Conclusions

The relationship between operating conditions and the occurrence of the magnetic arc blow in plasma arc cutting was reported. With increasing arc current, B_{th} decreases because arc plasma is more deflected by the Lorentz force, and B_{th} also decreases with decreasing main gas flow rate because the electrical insulation between the plasma jet and the nozzle become less effective. If the nozzle diameter is small, the deflected arc plasma is likely to contact with the nozzle wall. In order to suppress the occurrence of the double arc, arc plasma should be operated at lower current, higher main gas flow rate with larger nozzle diameter.

Magnetic shielding on the torch is also effective to suppress the double arc without changing operating conditions.

References

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