AIR PLASMA CUTTING......

Development of air-cooled and non-transferred air plasma arc cutting machine

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1. Introduction

Plasma cutting methods have been used for some time on steel, stainless steel, aluminium alloy and other metals. Low-current range transferred air plasma arc cutting machines are easy to operate, highly efficient, offer low cost operation and have become indispensable in cutting this metal plate [1,2].

However, a transferred air plasma arc cutting machine generates a plasma arc between a cutting torch electrode and the material being cut, limiting it to cutting conductive materials and preventing it from cutting non-metals.

Recent increasing demand for plastic, fireproof board and other non-metals makes desirable the development of an easy-to-use, highly efficient method for cutting these materials. Based on this background, development was begun on a non-transferred air plasma arc cutting machine that can cut non-metals as well as metals. The objective was to develop a non-transferred air plasma arc cutting machine that would be compact, lightweight, portable, easy-to-use, highly efficient and inexpensive. The non-transferred air plasma arc cutting machine used in experimental testing uses air for its plasma gas and is made up of a plasma torch, cutting power supply, and an air compressor for supplying compressed air.

The main tasks in engineering a non-transferred air plasma arc cutting machine that uses air for its plasma gas are: (1) building a nozzle that will have low wear when used in a high-temperature oxygen environment; and (2) forming a high-density plasma jet that performs high-speed, high-precision cutting.

To achieve these objectives, a few nozzles and plasma jet characteristics were tested to find the best nozzle material and shape. In testing for improvement in the portability of the non-transferred air plasma arc cutting machine, it was found that an inverter-controlled cutting power supply provided further compactness and lightness. Using a plasma torch with a nozzle suited to plasma cutting and inverter-controlled cutting power, the characteristics of different materials were examined.

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2. Investigation of plasma characteristics

2.1 *Configuration of experimental equipment and experimental method*

The configuration of the air-cooled and non-transferred air plasma cutting machine used in the experiment is shown in Fig. 1. The plasma torch structure's nozzle section divides the flow quantity Q (l/min) of compressed air supplied by the compressor into nozzle cooling gas and plasma generating gas. The cross-sectional area ratio of nozzle cooling gas to plasma generating gas at the air passage is 8:1. The electrodes

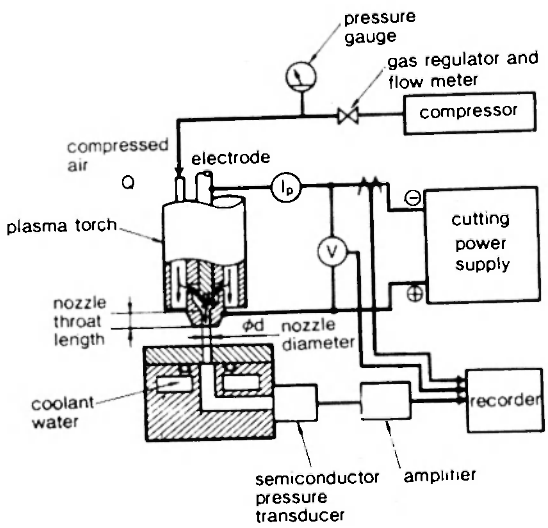

Fig. 1. Configuration of experimental equipment

have been made more wear-resistant by embedding hafnium into the copper electrode tips. Because an important task in non-transferred plasma is making the nozzle durable and controlling the shape of the plasma jet, the nozzle wear, the distribution of pressure, and the shape of the plasma jets were measured.

The nozzle wear quantity changes according to nozzle shape, nozzle material, nozzle cooling method, and types of gases used in generating the plasma. The shape of the nozzle used in the experiment is shown in Fig. 2. The three types of nozzle shape are the short throat length A-type, the long throat length B-type, and the one used in the transferred air plasma cutting machine, the C-type. For nozzle materials, the five types shown in Table 1 that have comparatively high thermal conductivity at high melting points were selected. Two types of nozzle cooling methods were compared : water cooling and air cooling.

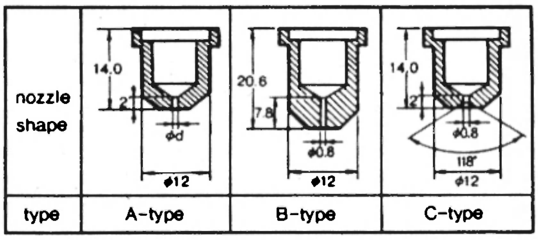

Fig. 2. Nozzle shapes used in the experiments

Pressure distribution in the plasma jet was measured in a water-cooled copper block equipped with the semiconductor pressure transducer shown in Fig. 1. A camera photographed the shape of the plasma jet flame.

2.2 *Experimental results and observations*

2.2.1 *Nozzle wear quantities*

Table 1 shows nozzle wear quantities of different nozzle materials. Copper nozzles had the lowest wear. It is believed that when plasma is generated, the nozzle interior becomes a high-temperature oxygen environment that causes the melting point and thermal conductivity of the nozzle material's oxide to affect nozzle wear. For the reason, comparative observations were made of melting points and thermal conductivity in the oxides of the copper (Cu) and hafnium (Hf) nozzles that had low wear in the experiment.

Copper oxide (Cu_2O) has a melting point of 1509 K and a therman conductivity of 5.44 (W/m·K), and hafnium oxide (HfO_2) has a melting point of 3085 K and a thermal conductivity of 2.64 (W/m·K) [3]. The Cu_2O melting point temperature is about half, but thermal conductivity about twice, that of HfO_2. The reason that the copper nozzle wear is lower than that of the hafnium nozzle is thought to be that Cu_2O thermal conductivity is higher than that of HfO_2, thus providing higher cooling efficiency at the cooled area of the nozzle's external circumference.

Table 1. Comparison of nozzle wear quantities of different nozzle materials

Material	Physical properties		Test condition				Results
	Melting point (K)	Thermal conductivity (W/m·K)	Current (a)	Arcing time (s)	Nozzle ϕd (mm)	Nozzle Type	Nozzle wear (mg)
Hastelloy X	1580	9.55	10	360	0.8	A	124.0
Cr	2170	61.50	15	360	1.0	A	123.0
Cu-10Hf	—	—	15	360	0.8	B	43.0
Cu	1356	330	15	360	0.8	B	18.0
Hf	2423	22.6	15	360	0.8	A	53.0

The amount of nozzle wear with different methods of nozzle cooling are shown in Fig. 3. The air plasma generation cycle was 60% duty (repeating a pattern of generating air plasma for 6 min and resting for 4 min) using A-and B-type copper nozzles. Figure 3 shows also the amount of nozzle wear for the B-type with its low plasma current I_P of 5 A.

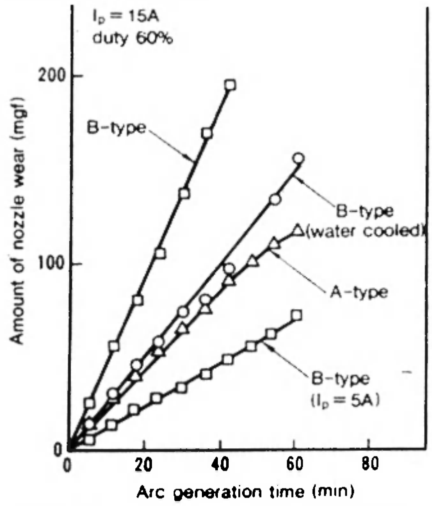

Fig. 3. Relation between arc generating time and nozzle wear

The nozzles in sequence from lowest to highest amounts of wear are : the air-cooled A-type, the water-cooled B-type (using a water flow 1.3 *l*/min), and the air-cooled B-type. The major reasons for the low wear with the A-type nozzle are : the anode spot is at the angled section of the nozzle, there is little fluctuation in the throat length direction of the nozzle outlet, and there is no heat build-up in the nozzle interior. However, because the A-type nozzle's wear pattern is generated at the nozzle outlet's angled section, it has the disadvantages of a changing nozzle outlet diameter and of not being able to provide a uniform cutting pattern.

The B-type long throat length nozzle produces greater nozzle wear than the A-type, but the anode spot inside the nozzle throat gives an exceedingly low amount of outlet wear.

It should be noted that using nitrogen for the plasma generating gas reduces the nozzle wear to about 1/40th that of air.

2.2.2. *Pressure distribution and shape of the plasma jet*

The measurement of pressure distribution in the air plasma jet, the fact that the B-type nozzle has a plasma jet pressure at the centre which is about twice as high as the C-type, and that it is pinched in the direction of the nozzle's diameter are shown in Fig. 4. It thus forms a

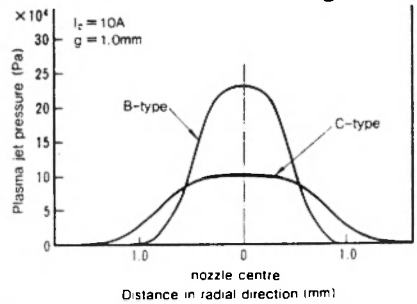

Fig. 4. Pressure distribution in the air plasma jet

long, narrow plasma jet that is effective for cutting narrow widths. Figure 5 is a photograph that allows the long, narrow shape of the B-type nozzle's plasma jet to be seen. The C-type's anode spot is generated at the nozzle outlet and causes the plasma jet flame to spread out from the nozzle outlet.

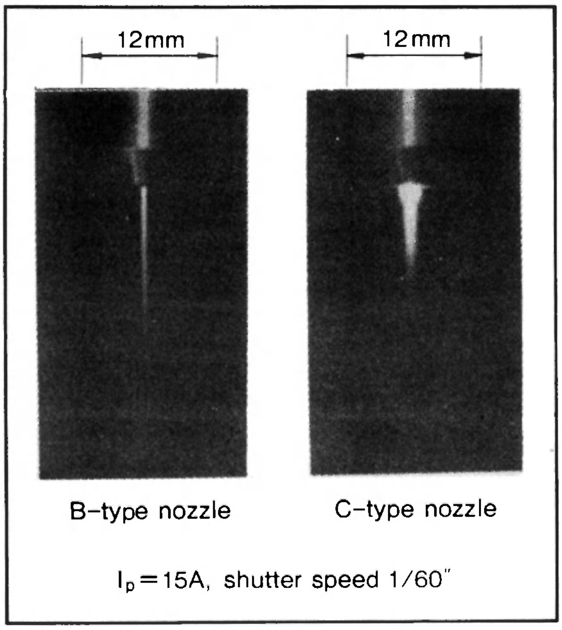

Fig. 5. Shapes of air plasma jets

The above tests permitted us to determine that the nozzle best-suited for non-transferred air plasma arc cutting is the copper B-type.

3. Cutting characteristics

The materials used in tests of cutting characteristics were 2-9 mm thick PMMA and fireproof board and 1-3.2 mm thick mild steel plate. A plasma current I_P of 15 A or less was selected for cutting. Cutting tests were performed under different plasma currents I_P and cutting speeds v to derive cutting widths, kerf angles θ, and jet flame curves δ from cutting shapes. The kerf angle θ is calculated from $\tan^{-1}\{(b-a)/2t\}$, where a is the cutting width, b is the bottom cutting width and t is thickness. Jet flame curve δ is derived by measuring the different length c between the top and bottom surface cuts at the end of plasma cutting, and calculating $\tan^{-1}(c/t)$.

3.1 *Cutting characteristics with non-metals*

The cutting characteristics for PMMA are shown in Fig. 6. PMMA's low softening point of 100°C allows cutting by a low plasma current I_P of 5 A. The width of the plasma jet flame emitted by the nozzle gives the bottom cut a width that is slightly greater than the top cut's. The plasma jet curve δ increases in relation to the increase in cutting speed, and so increases both the top and bottom cut widths and the kerf angle θ.

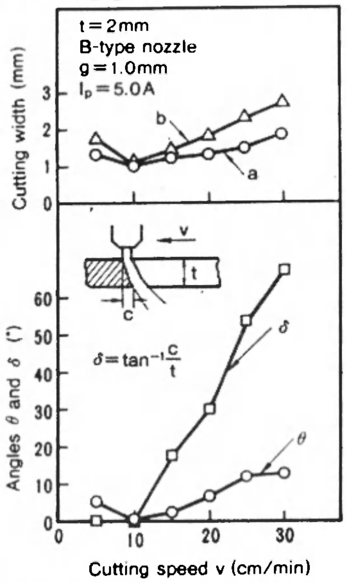

Fig. 6. Cutting characteristics of PMMA

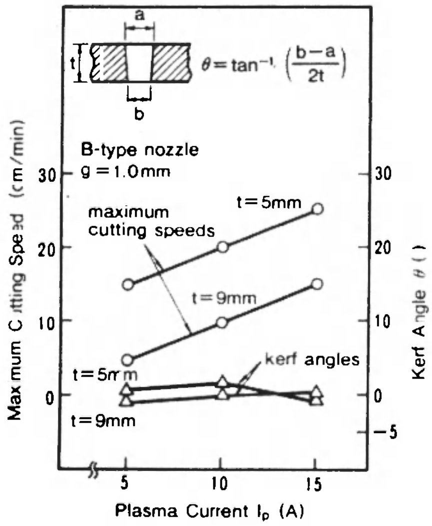

Fig. 7. Cutting characteristics for fireproof board

Thus, small kerf angle cuts become possible at cutting speeds of 10-20 cm/min.

The cutting characteristics for fireproof board, another non-metallic material, are shown in Fig. 7. The maximum cutting speed shown in Fig. 7 is that at which the plasma jet passing through the material gives a uniform width cut in the bottom surface. The maximum speed for cutting fireproof board is characterized as decreasing when the thickness of the board is increased and as linearly increasing when plasma current I_P increases. Kerf angle θ is also very good and low, at less than 3°.

The appearance of a cut section of one of these non-metallic materials is shown in Fig. 8. PMMA cut at

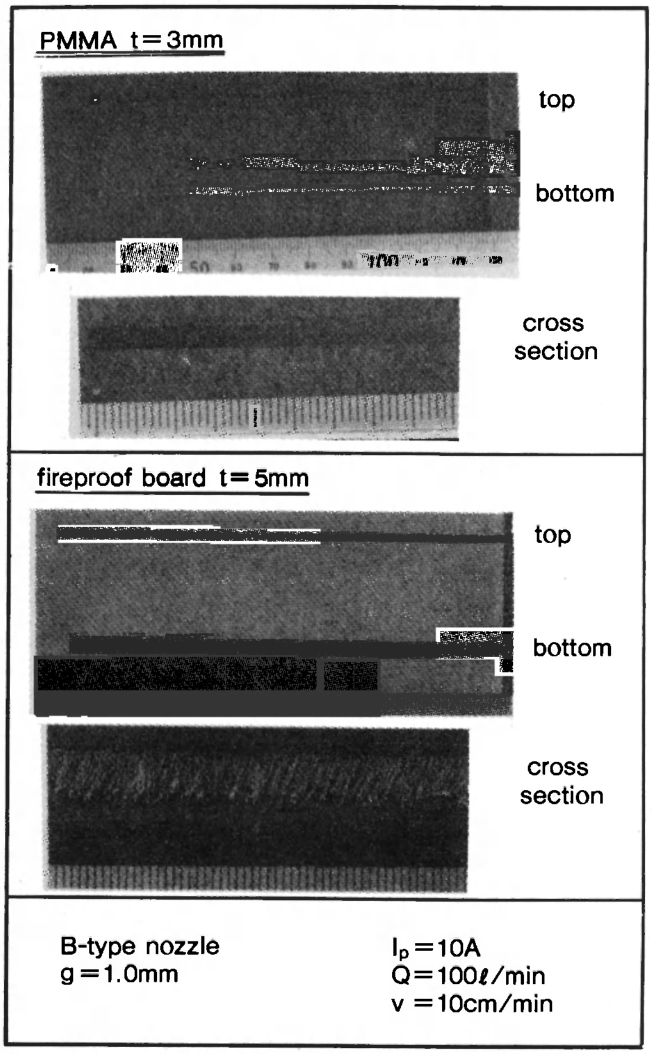

Fig. 8. Appearance of cut section in non-metallic materials

10 cm/min shows no adherence of dross on either the top or bottom surfaces, but beautifully smooth cross-sections that still maintain their transparency.

The high temperature plasma jet first melts part of the fireproof board to form a layer which then solidifies, and a drag-line has appeared in the cut cross-section. Adhering to the bottom surface of the cut fireproof board is a dross, the main component of which is SiO_2. This dross can, however, be easily removed by hand.

3.2. *Cutting characteristics for metals*

The non-transferred air plasma arc cutting machine characteristics in cutting mild steel plate are shown in Fig. 9. The maximum cutting speed declines rapidly as thicker plates are cut. Faster speeds were attempted

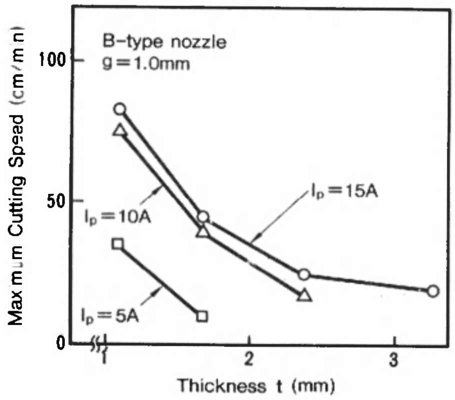

Fig. 9. Relationship between thickness and maximum cutting speed for mild steel

using a contact cutting method is which the nozzle touches and the anode spot moves on to the material being cut. An A-type nozzle was used in which the anode spot for contact cutting moves easily over the materials being cut. Table 2 shows the maximum cutting speeds

Table 2. Maximum speed of contact cutting

		Maximum cutting speed (cm/min)	
Thickness t (mm)	Plasma current I_P (A)	Non-contact cutting	Contact cutting
1.0	5.0	40.0	70.0
2.0	10.0	20.0	45.0
3.2	15.0	25.0	60.0

for a A-type nozzle in contact cutting and for a B-type nozzle in non-contact cutting. This allowed the discovery that maximum speeds with contact cutting are faster than those with non-contact cutting and that a contact method in which the nozzle actually touches the material being cut can be used for high-speed metal cutting.

The appearance of a mild steel plate section cut by contact cutting is shown in Fig. 10. The low 10 A plasma current I_P causes dross to adhere to the bottom surface of the plate but gives a uniform cut width.

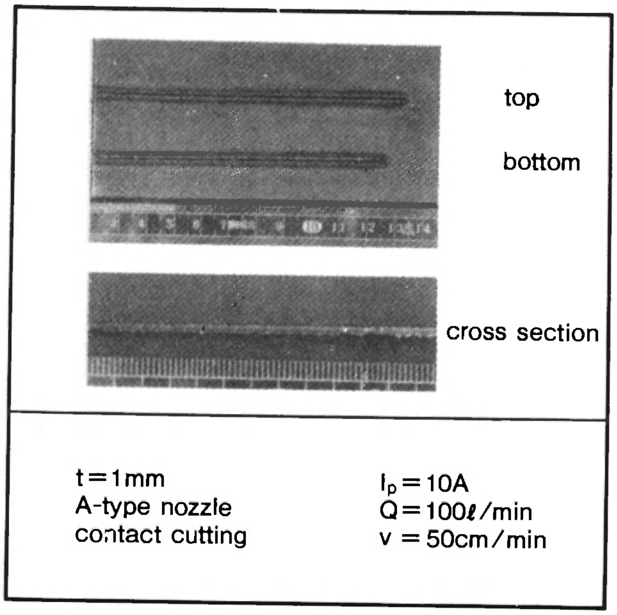

Fig. 10. Appearance of cut section in mild steel plate.

The shunting current on the cut material side was also measured to find out the degree that the anode spot moves along the material during contact cutting. Figure 11 shows the measurement methods and results. Using a copper plate with a slit, a plasma jet was generated at the top edge of the slit (slit width, 1.5 mm and top edge curve, R = 0.75 mm) and shunt current $I_1$was measured. Shunt current I_1 increases as stand-off g gets shorter. With the nozzle in contact with the slit copper plate, 82.5% of the plasma current I_P transfers to the slit copper plate as shunt current I_1. Because the plasma current can be shunted to the cut material, placing the nozzle in contact with the metal material in this way provides high-speed cutting and low nozzle wear.

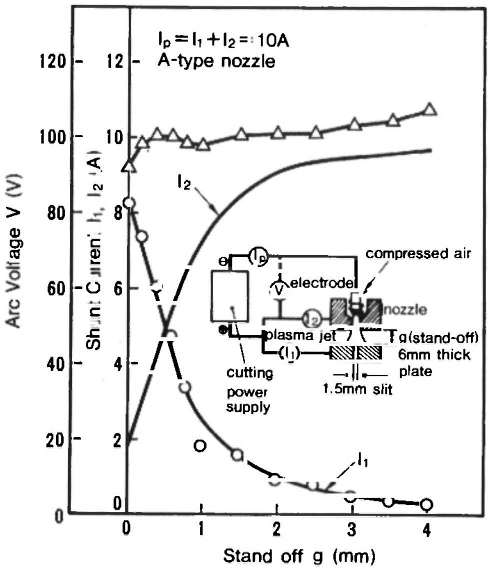

Fig. 11. Shunt current and arc voltage

4. Specifications and appearance of the air-cooled, non-transferred air plasma arc cutting machine

Table 3 gives the main specifications of the developed cutting machine. The specifications shown in Table 3 were determined based on the following design concepts.

1. Using low-cost compressed air for the gas to cool the nozzle and generate the plasma provides inexpensive cutting.
2. Use of inverter control allows the cutting power supply to be light and compact, thus easy to carry around.
3. The 15-A single-phase rated current gives a low current range with which even a small supply can be used to provide a simple cutting tool.
4. Just changing the nozzle on the plasma torch gives a combination-type cutting tool for either contact or non contact cutting.

The circuit configuration of the inverter controlled cutting power supply is shown in Fig. 12. This circuit configuration is a pulse width feedback control type that controls output current to rated levels and is equipped with an output control knob for setting output current. The low, light cutting power supply has a

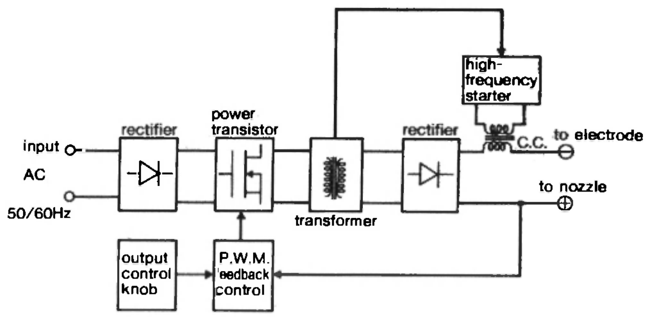

Fig. 12. Circuit configuration of cutting power supply

Table 3. Specifications for the developed air-cooled, non-transferred air plasma arc cutting machine

Power	Rated output current	5-15 A	
	Primary input voltage	Single phase 220V, 50 Hz,	
	Rated duty cycle	40% (10 min cycles)	
	Control method	Inverter	
		About 19 kg	
Torch	Rated Current	15 A	
	Rated duty cycle	40% (10 min cycles)	
	Gas used	Compressed air	
	Weight	About 200 g	
	Cutting method	Contact/non-contact	
Cutting ability	Non-metal	PMMA	6 mm
		Fireproof board	9 mm
		Composite board	9 mm
	Metal	Steel	3.2 mm
		Stainless steel	3.2 mm
		Aluminium alloy	1.0 mm

high-frequency inverter control of 20 kHz. Figure 13 shows the air-cooled, non-transferred air plasma are cutting machine that was developed. The output control knobs built into the power supply's front panel can be used to set cutting current in steps from minimum to rated current as required by cutting conditions.

Fig. 13. Appearance of the developed air-cooled and non transferred air plasma arc cutting machine

5. Conclusion

The best nozzle shape and plasma jet characteristics for cutting metallic and non-metallic materials have been determined, and an air-cooled and non-transferred air plasma arc cutting machine with a current capacity of 15 A or less has been developed.

1. The B-type nozzle is best suited for the cutting of non-metallic materials because it can cut 2-9 mm thick PMMA and fireproof board at speeds of 15-20 cm/min and has a kerf angle of 3-6°.
2. The contact method for cutting metals, in which the nozzle touches the material to be cut, provides high speeds on 3.2 mm thick mild steel that are about 2.4 times as fast (60 cm/min) as the non-contact method.

References

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