MIG Welding under High Pressure Ar Arc Atmosphere†

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Abstract

MIC welding under high pressure Ar atmosphere (0-6 MPa) has been studied by mean of welding chamber. Effect of pressure on the arc voltage, welding current and weld metal shape are studied. MIG welding process by constant arc voltage condition and constant arc length condition are compared.

The main results are summarized as follows;

1) *Increasing pressure from 0 to 6 MPa, arc became to constrictive, plural cathode spots and unstable arc were observed. Brightness of arc column was increased. A lot of spattered droplets and fine particles were produced.*
2) *As welding was carried out using constant arc voltage condition, welding current was decreased above about 2 MPa. Decreasing of heat input under high pressure was observed.*
   Crowned weld metals, narrow bead wide, weld metals which is not deep penetration were shown.
3) *As welding was carried out using constant arc length condition, arc voltage was raised remarkably with pressure then also, heat input was increased.*
   Crowned welds were not obtained. Bead wide, penetration depth were not changed remarkably increasing pressure from 0 MPa to 6 MPa. Area of HAZ was affected by increasing pressure, tensile and bending test results were satisfactory under condition of this study.
4) *It was estimated that constant arc length condition is good for MIG welding process under high pressure arc atmosphere.*

KEY WORDS: (MIG Welding) (Dry Hyperbaric Welding) (Under Water Welding) (High Pressure Welding)

1. Introduction

Dry hyperbaric welding process (MMA, TIG and MIG) are used for the construction or the repair of pipe line and offshore structures. An environmental welding atmosphere became more high pressure. Dry hyperbaric TIG and MMA welding process have been studied up to 5 MPa[1-2], but on MIG welding under high pressure over 3 MPa[3-10], there seem to be very few study on that.

The purpose of this study is to obtain the fundamental data on the MIG welding process under high pressure Ar atmosphere up to 6 MPa. The effect of pressure on the welding arc phenomena, weld metal formation, spattering ratio, microstructure of weld, cooling rate of HAZ and joint strength are studied.

2. Experimental Procedures

Welding apparatus designed to maintain controlled high pressure arc atmosphere are used. A stainless steel (SUS316) chamber of about 1.8 m^3 in volume was made to maintain desired gas pressure and composition, as shown in **Fig. 1.** The atmospheric pressure in the chamber can be changed from 0.1 torr to 6.5 MPa.

The head of an automatic MIG, TIG and sub-marged arc welding machine can be set in this pressure chamber.

Welds are performed with direct current power source which has an OCV of 80V (1000A) and transistorized power source which has an OCV 45V (800A).

SUS304 stainless steel plate and its consumable electrode wire were used, because it was purposed to apply the stainless steel for offshore structures that be welded by high pressure MIG process. But the necessary was produced that to make clear of experimental results

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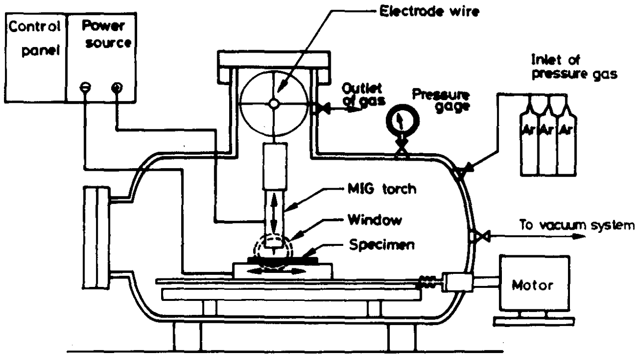

Fig. 1 Schematic illustration of pressure chamber and equipment

obtained at high pressure by MIG process using stainless steel. Then, mild steel plate and its electrode wire were used because they had quite low content of Ni, Cr and Mn elements.

The chemical compositions of materials used are shown in **Table 1**. Base plates of 200 x 100 x 12 mm size and electrode wires of 1.6 mm in diameter, whose surfaces had been ground and cleaned to remove seal, dirt and grease, were set in the chamber. The chamber was evacuated to a pressure of 0.1 torr and then it was filled with the pressurized Ar gas.

The SUS304 steel plates were welded by bead-on-plate type welding with the stainless steel electrode wire was positive, using direct current-constant potential characteristic power source. Welding current and arc voltage were changed. The distance between the contact tip and the base metal was 30 mm.

As increasing of pressure of Ar arc atmosphere, it was found that the arc length became remarkable short and a crowned weld metals were observed. Then, direct current drooping characteristics power source was applied to control the arc length, to prevent the weld defects. Apparent arc length was adjusted by manual operation.

The surface appearance such as spattering, bead shape and microstructure of welds were observed. Cooling rates of HAZ were measured also. Weld joint strength from some sound samples was tested by tensile testing machine.

Table 1 Chemical compositions of base metals and electrode wires (wt%)

Material	Thickness of base metal (mm)	C	Si	Mn	P	S	Ni	Cr
SS 41	12	0.13	0.21	1.13	0.019	0.006	—	—
SUS 304	12	0.06	0.70	0.99	0.029	0.009	8.51	18.18

Material	Electrode diameter (mm)	C	Si	Mn	P	S	Ni	Cr	Mo	N
YM-26	1.6	0.07	0.81	1.51	0.015	0.008	—	—	—	—
MG 308L	1.6	0.010	0.37	2.38	0.024	0.007	10.50	19.68	0.08	0.024

3. Experimental Results and Discussions

3.1 MIG welding under high pressure Ar atmosphere by means of direct current constant potential power source (constant arc voltage condition)

The study on dry hyperbaric MIG welding has been previously carried out mainly by using constant potential power source (C.P.P.S.) and pressurized welding atmosphere of max. about 3 MPa.

In this study, at the first place, C.P.P.S was used to research on MIG welding phenomena under high pressure Ar atmosphere of 6 MPa. Welding parameters and material were as follows: Arc voltage 30V, Wire melting rate (W.M.R.) 183 mm/sec, Welding speed 4 mm/sec and SUS304 stainless steel.

Figure 2 shows the effect of the pressure on the welding current. Interestingly, the welding current increases with the Ar pressure up to 1 MPa, and after then, it falls as the Ar pressure further increase.

Increasing of welding current due to increasing with the pressure up to about 1 MPa, is estimated that the effect by change of arc length. It became remarkably shorter than that of 0 MPa (atmospheric pressure). Falling tendency of the welding current over 1 MPa, it can be explained as follow the electric resistance of arc atmosphere increases with increasing of Ar pressure and high pressure atmosphere makes the cooling effect of arc strong.

This general trend was observed at another welding condition of 35V, W.M.R. 95 mm/sec. This results have an

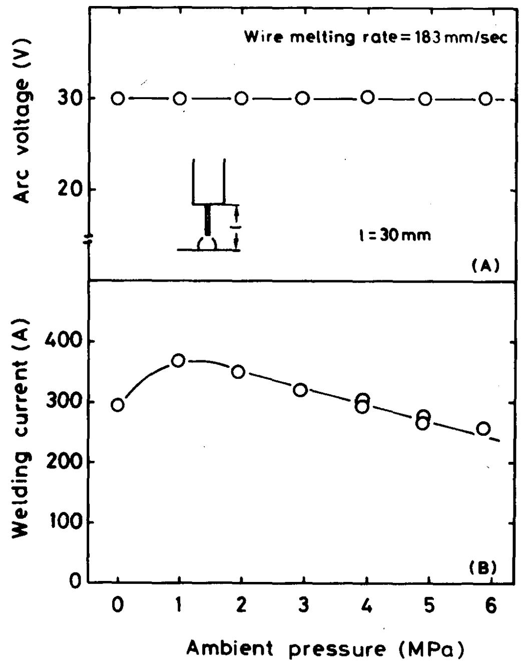

Fig. 2 Effect of ambient pressure on welding current

idea of the coming on decrease of heat input of MIG welding under high pressure.

The arc shapes observed in the high pressure atmosphere are shown in **Fig. 3**. At 0 MPa (atmospheric pressure), the arc shape is likely bell type, but at high pressure, it became to constrictive and arc length became shorter and its brightness was increasing than that of 0 MPa.

Figure 4 shows schematic illustration of arc shape as a function of pressure, in the atmospheric pressure (0 MPa), anode spot (a-b area) is made at molten metal surface of electrode tip, and then anode spot has concentrated at tip of electrode and its surface area decreases. It is seen that the detachment force of molten metals from electrode would probably decrease as the pressure increase.

Then electrode wire melting rate (W.M.R.) was observed. **Figure 5** shows the measured results of melting rate of wire as a function of Ar pressure under the conditions on 35V, 300A.

It can be seen clearly from the figure that wire melting rate decrease with Ar pressure up to about 0.5 ~ 0.6 MPa and then it increase slightly as the Ar pressure further raise.

To explain that the result, the following reasons are considered;

1) The detachment force of molten metals from electrode is effected by change of the shape of electrode tip and arc phenomena in high pressure[3, 11, 12].
2) The effect of wire extension length caused by decreasing of arc length[3, 8, 13]. The typical photographs showing the weld metal appearances with welding condition of 30V, W.M.R. 183 mm/sec are shown in **Fig. 6**.

In high pressure range, a lot of spattered metals and nonuniform bead shape are observed. Weld cross sections

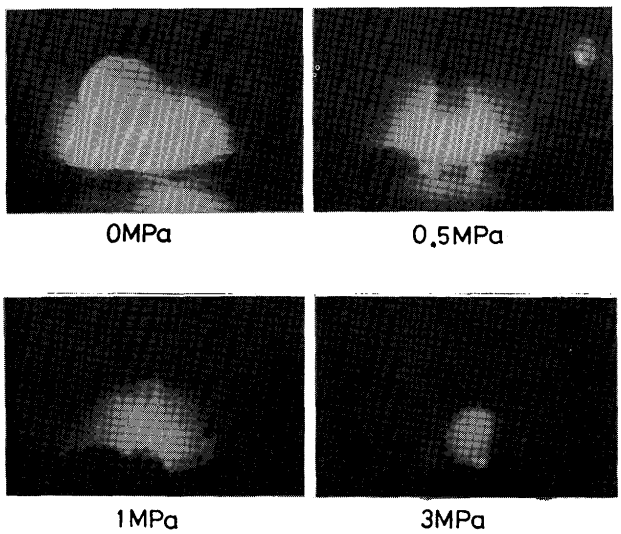

Fig. 3 Effect of ambient pressure on arc shapes

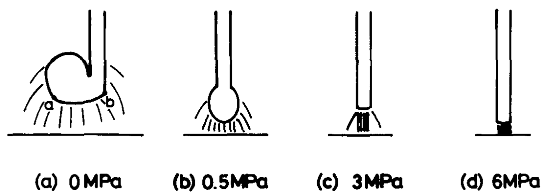

Fig. 4 Schematic illustration of arc shapes

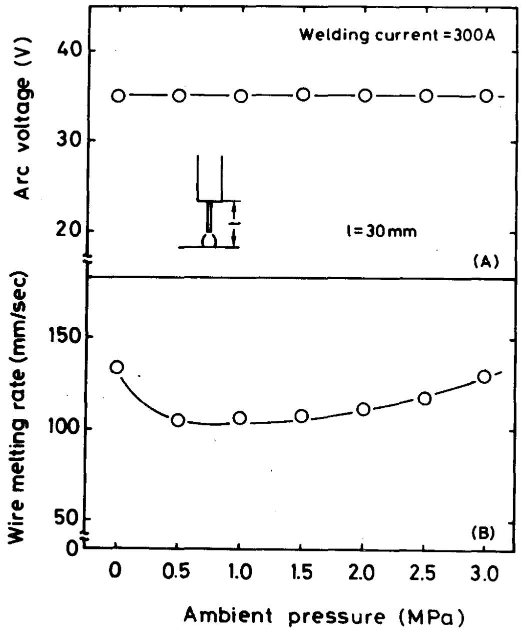

Fig. 5 Effect of ambient pressure on wire melting rate (W.M.R.)

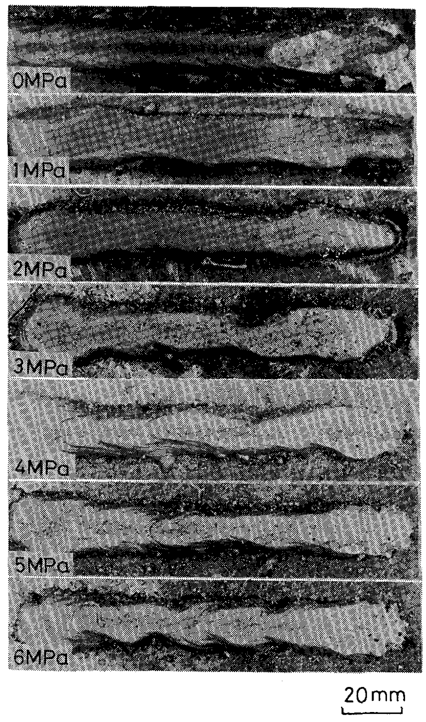

Fig. 6 Effect of ambient pressure on appearances of weld beads

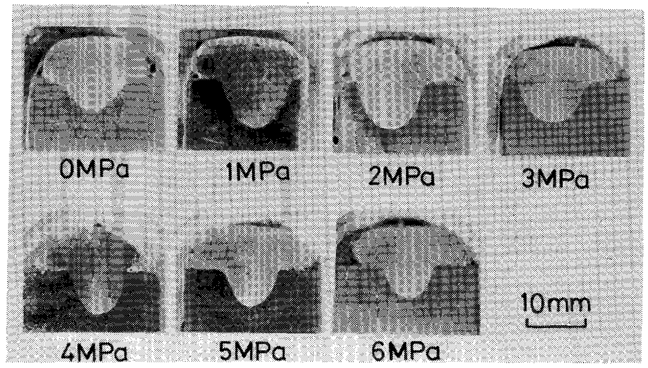

Fig. 7 Effect of ambient pressure on cross sections of welds

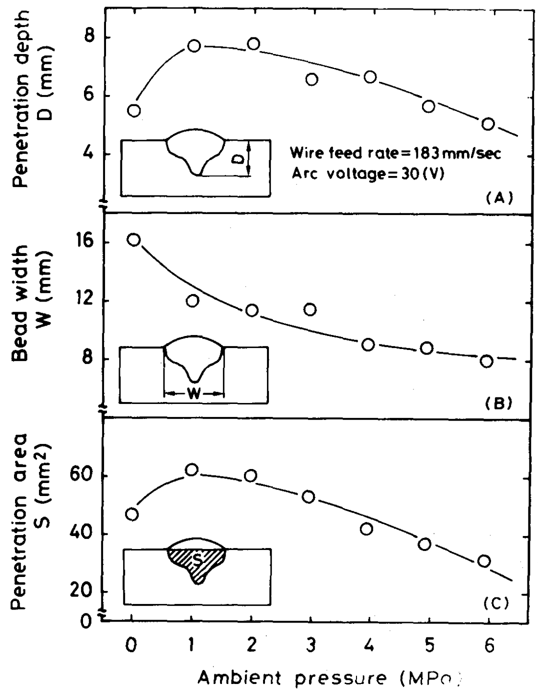

Fig. 8 Effect of ambient pressure on penetration depth (A), bead width (B) and penetration area (C)

are shown in **Fig. 7**. Penetration depth (A), area (C) and bead wide (B) were measured and shown in **Fig. 8**. (A), (B) and (C) are decreased at high pressure range respectively. It was clear that the condition of constant arc voltage by constant potential characteristic power source is not good for high pressure MIG welding.

Then, method of controlled arc length and constant W.M.R. by drooping characteristic power source was applied for high pressure MIG welding.

3.2 MIG welding under high pressure Ar atmosphere by means of drooping characteristic power source (constant arc length condition)

The welding was carried out using following parameters; arc length (L) 5 mm & 10 mm, welding current 250A, 350A & 450A. Relation between arc voltage and Ar

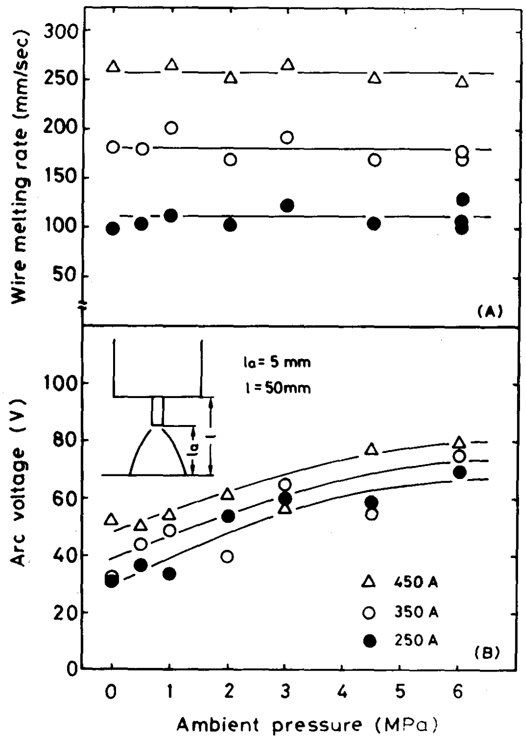

Fig. 9 Effect of ambient pressure on arc voltage (arc length = 5 mm)

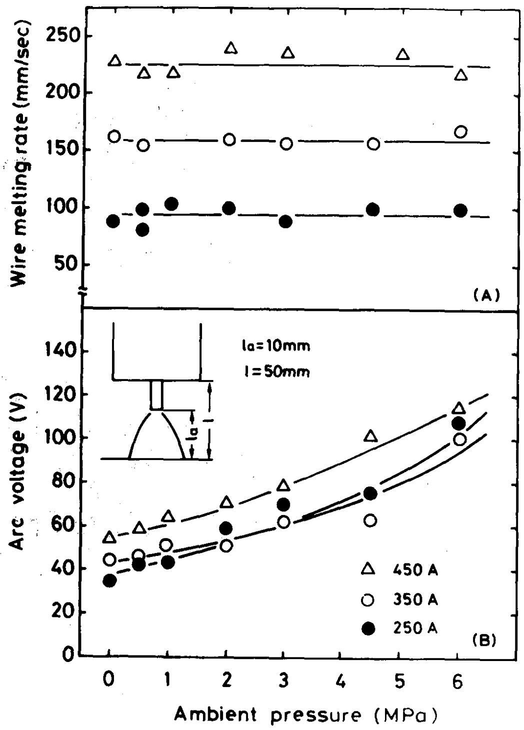

Fig. 10 Effect of ambient pressure on arc voltage (arc length = 10 mm)

pressure is shown in **Fig. 9** (L = 5 mm) and **Fig. 10** (L = 10 mm) respectively. Arc voltage was raised remarkably by Ar pressure increased.

This results have a idea of the coming on increase of

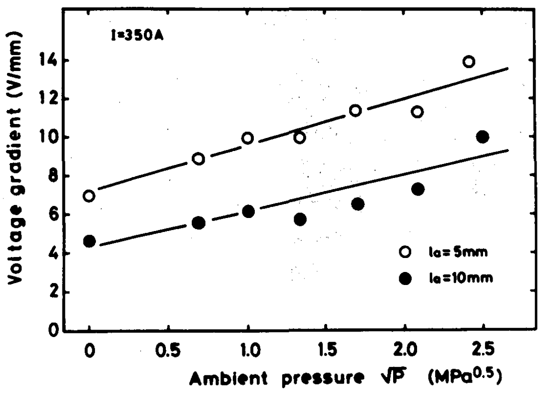

Fig. 11 Relation between voltage gradient and square root of the ambient pressure

heat input of MIG welding under high pressure. And this results are opposite to the previous idea by constant arc voltage condition. The similar results on the behaviour of arc voltage were reported by Y. SUGA[1], K. NISHIGUCHI[3], and M. Perlman[5]. Relation between voltage gradient and square root of the pressure is shown in **Fig. 11**. It can be seen clearly from this figure that voltage gradient obtained by MIG welding increase linearly with square root of the pressure at every arc length. The variations of arc voltage with arc length is plotted in **Fig. 12** for different Ar pressures. The relationship of arc length and arc voltage at a pressure given is shown clearly from these figures. This data is useful for high pressure MIG welding by arc voltage constant condition.

The typical photographs showing the arc shape with arc length 10 mm, 350A are displayed in **Fig. 13**. In high pressure atmosphere, the arc was constricted, brightness of arc column was increased, plural cathode spots and unstable arc were observed.

Also the arc was more and more obscured by clouds of fine particles and a lot of spattered droplets were observed on the surface of bead and base metals.

Unstability of arc was estimated by measuring of change of arc voltage. **Figure 14** shows the measured results of variation of arc voltage as a function of Ar pressures. The effect of pressure on the metal transfer mode is very important and interesting in the formation of the weld bead.

The typical photographs showing the metal transfer is displayed in **Fig. 15**. The welding parameters are L = 10 mm, 250A. In case of 0 MPa, droplets are produced at tip of electrode wire, but in high pressure, spray type droplet transfer was observed. In present paper, metal transfer characteristics was not discussed in detail. It may be discussed in another article in the near future.

The effect of pressure on the shapes of weld metal and welds structure were observed. The typical photographs

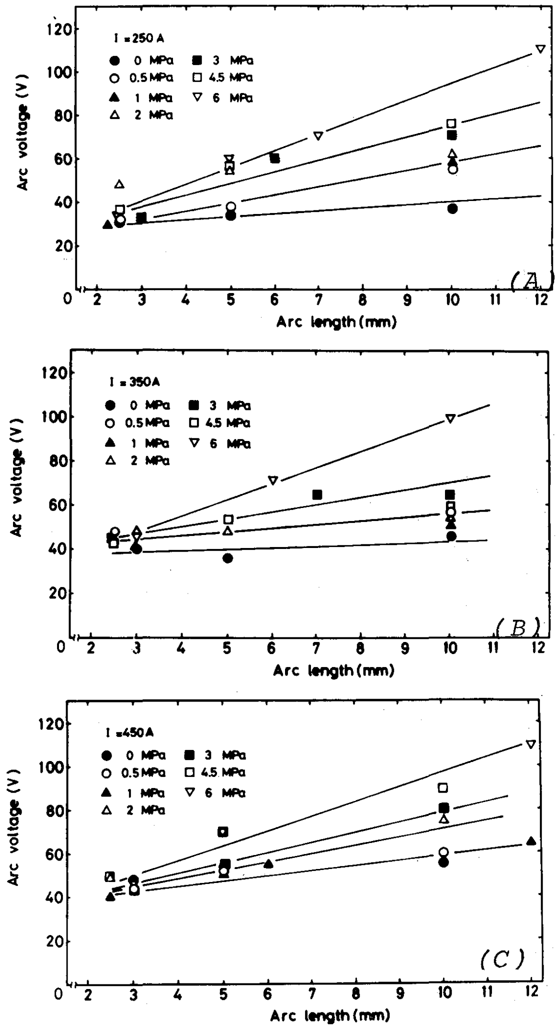

Fig. 12 Relation between arc voltage and arc length (A): 250A, (B): 350A and (C): 450A

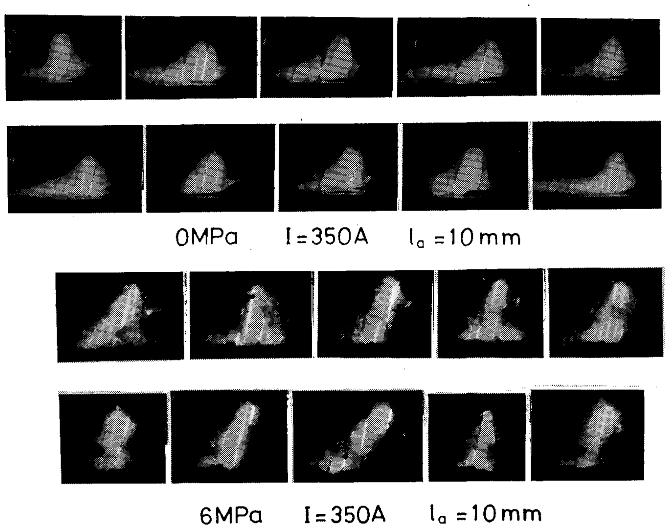

Fig. 13 Effect of ambient pressure on the arc shapes

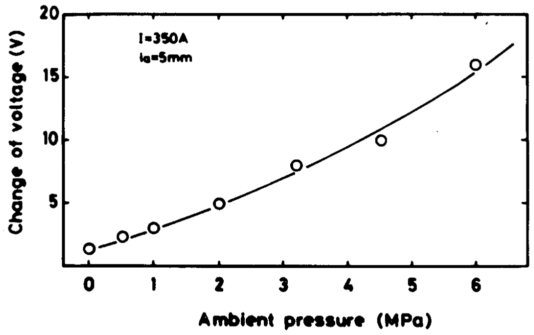

Fig. 14 Variation of arc voltage as a function of ambient pressure

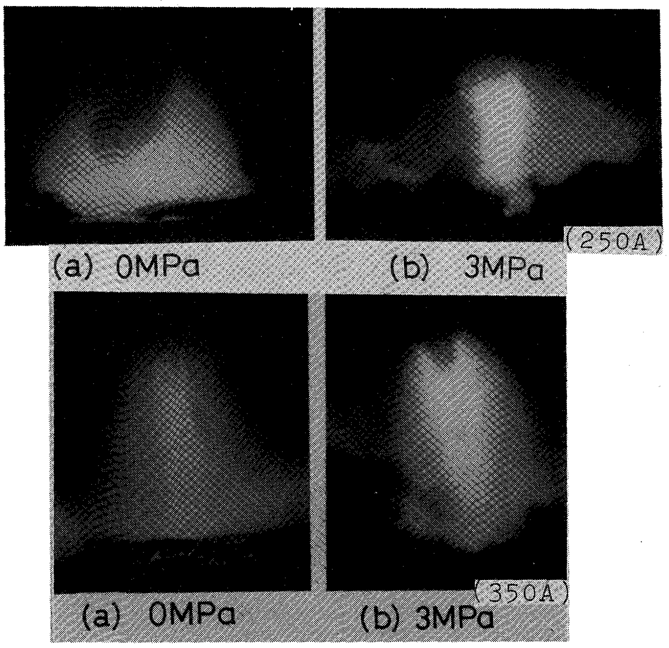

Fig. 15 Effect of ambient pressure on droplet transfer

showing the weld metal appearances with welding condition of arc length 5 mm and 10 mm, welding current 250A, 350A and 450A are shown in **Fig. 16** respectively.

A lot of spattered droplet were observed on the surface of weld bead at the high pressure, but it was known that the appearances obtained at 6 MPa were similar to that made at 0 MPa.

Weld cross sections are shown in **Fig. 17**. Crowned welds were not observed but flat welds were obtained.

Bead height (A), bead wide (B), penetration depth (C) and penetration area were measured and shown in **Fig. 18** and **Fig. 19** respectively.

Bead wide and penetration depth were not affected by pressure, but penetration area was increased with increasing of pressure. Consequently, it can be seen clearly from these results that the constant arc length condition by drooping characteristic power source is good for high pressure MIG welding process.

Transeverse section were taken through each bead on

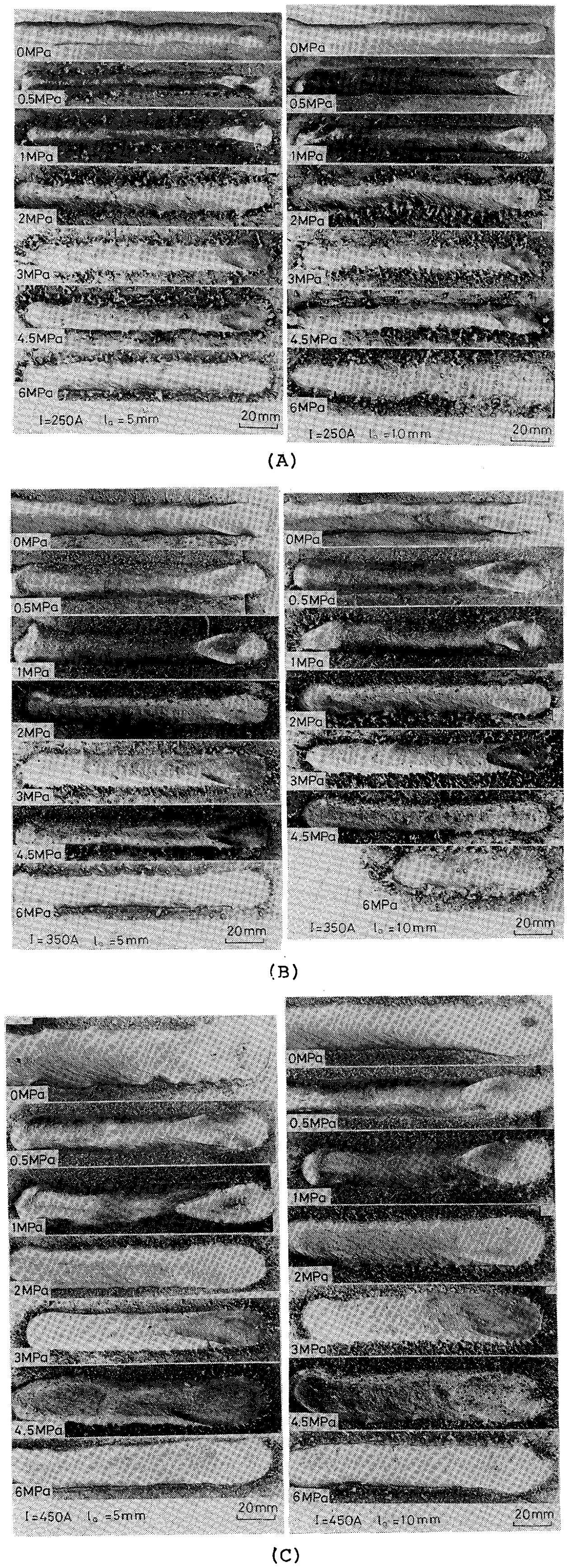

Fig. 16 Effect of ambient pressure on appearances of weld beads (A): 250A, (B): 350A and (C): 450A

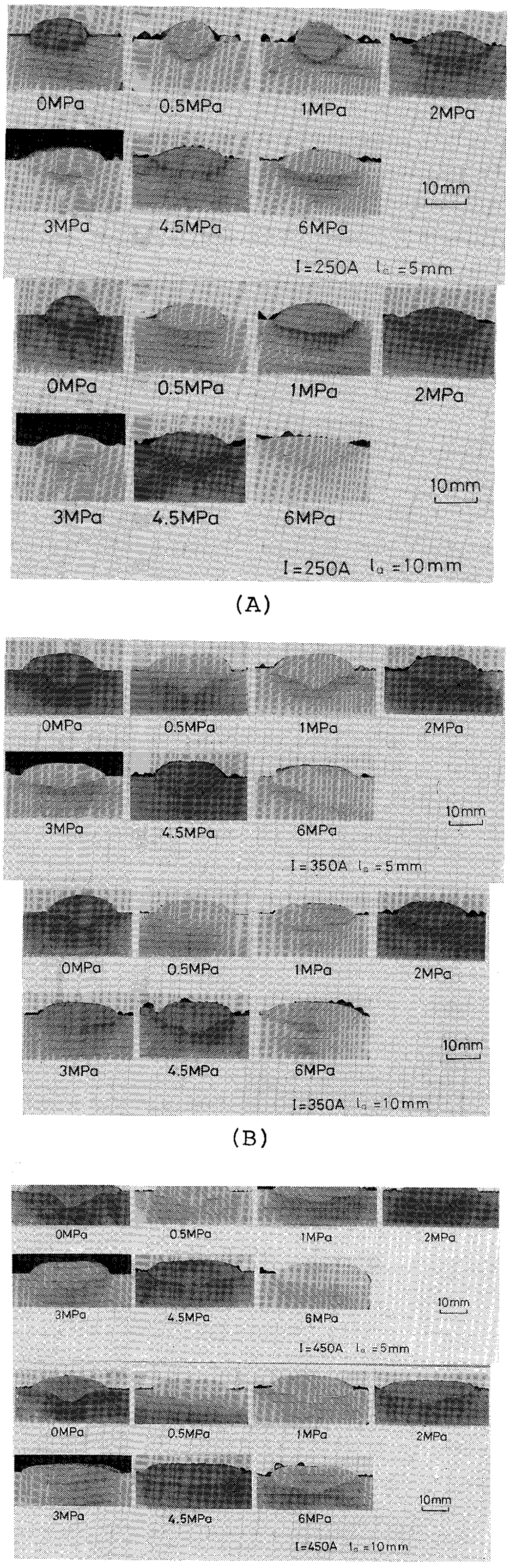

Fig. 17 Effect of ambient pressure on cross sections of welds (A): 250A, (B): 350A and (C): 450A

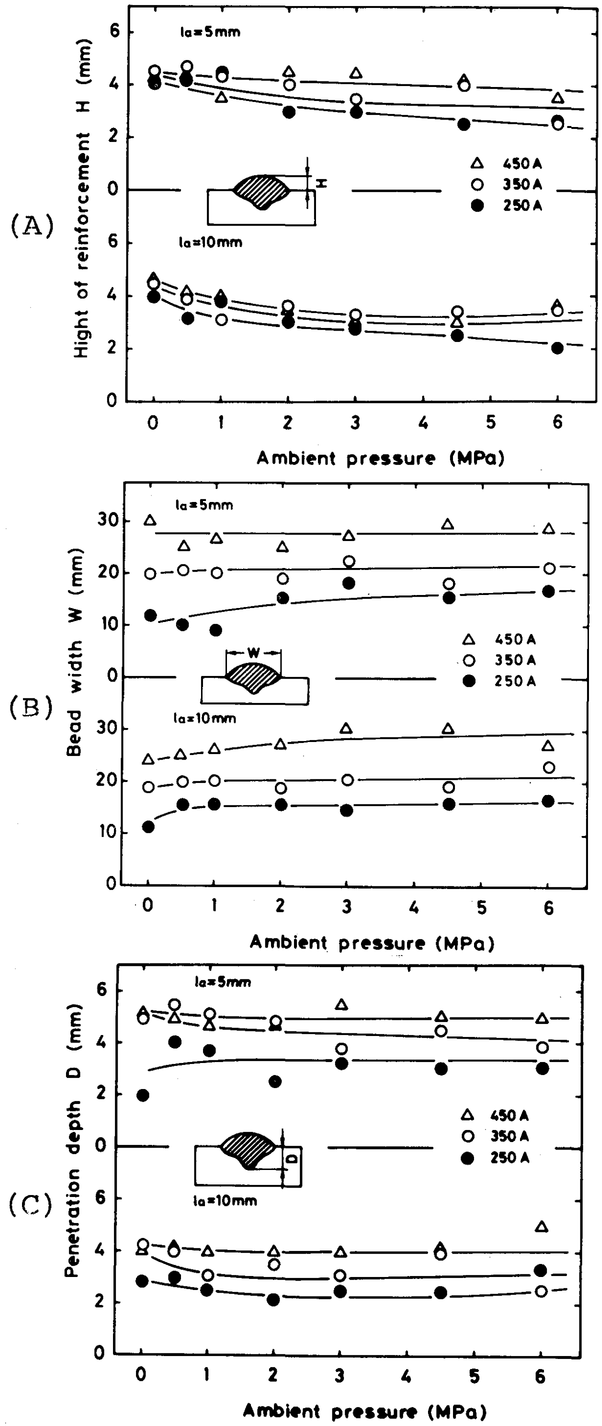

Fig. 18 Effect of ambient pressure on bead height (A), bead width (B) and penetration depth (C)

plate test piece for metallographic examination. **Figure 20** shows a microstructures of weld metal. Ferrite-Parlite structure is shown but particle ferrite was obtained at high pressure. A typical HAZ microstructures are shown in **Fig. 21**. Area of HAZ increased with increasing of pressure. It is estimated that heat input of HAZ obtained at 6 MPa is larger than that of 0 MPa.

Measurements of the weld thermal cycle in the heat-

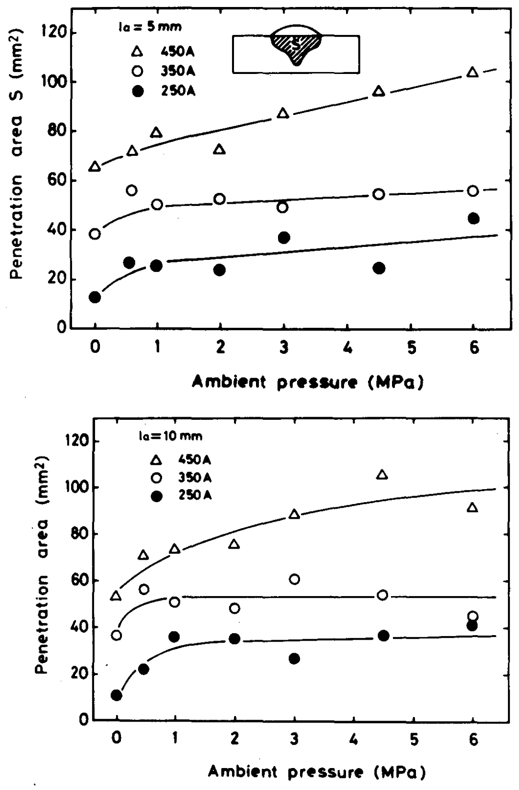

Fig. 19 Effect of ambient pressure on penetration area (A) L = 5 mm and (B) L = 10 mm

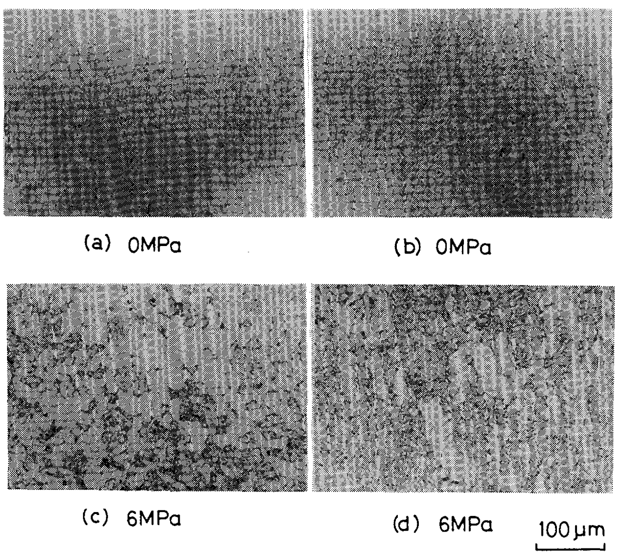

Fig. 20 Microstructures of weld metals

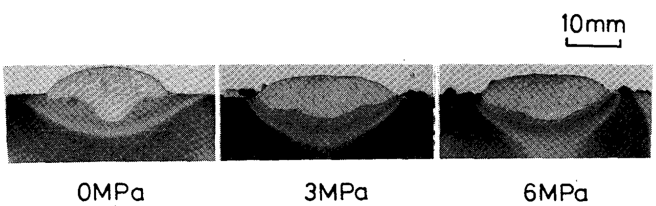

Fig. 21 Effect of ambient pressure on the shapes of heat affected zone of welds

affected base metal have been made using embeded thermocouples.

These results are shown in **Fig. 22**. The highest peak temperature was obtained by welding at 6 MPa.

At about more than 700 K cooling rate obtained at 6 MPa is faster than that of 0 MPa and 3 MPa but it becomes slightly slower less than about 660 K.

Spattering ratio is shown in **Fig. 23**. It was measured using following equation.

Spattering ratio =

$$\frac{\text{weight of collected droplets (g)}}{\text{weight of melted wire (g)}} \times 100$$

Increasing with pressure, the spattering ratio is increased. The cause of spattering generation is not known clearly yet, but it is estimated that the molten metals made at electrode tip were broken off then metal droplets were spattered.

On the other hand, base metal surface was covered by a lot of fine particles as described. Then fine particles were collected and analyzed by x-ray diffraction method. It was known that the particles were made by α-iron. The typical SEM photograph showing the fine particles are displayed in **Fig. 24**. The particles of about 1 μm in size were spherical. Tensile test and bending test on welds joints were carried out at room temperature. For the

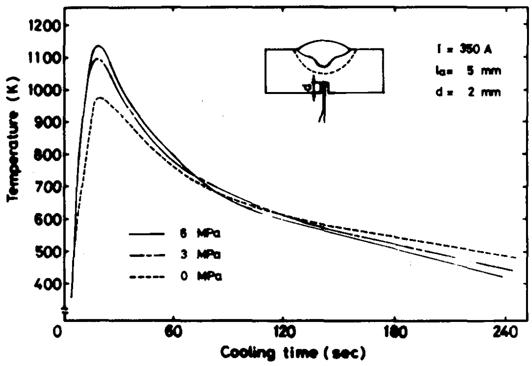

Fig. 22 Effect of ambient pressure on the thermal cycles at HAZ

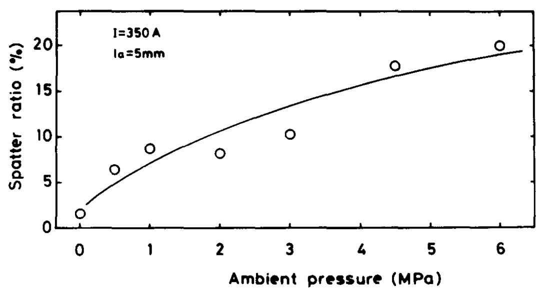

Fig. 23 Variation of spatter ratio as a function of ambient pressure

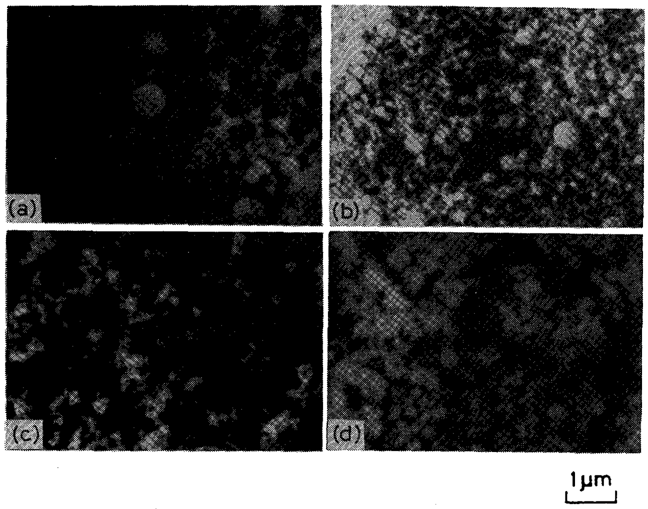

Fig. 24 Scanning electron micrographs of fine particles obtained at high pressure MIG welding (A): 0 MPa, (B): 0.5 MPa, (C): 4.5 MPa and (D): 6 MPa

welded joints, a single bevel butt edge preparation was used with a bevel angle of 60°, root face of 1 mm and root gap of 2 mm. Welds were completed by one pase with arc length 5 mm, welding current 350A. Test results of tension test are recorded in **Table 2**. On bending test, cracks and other defect at bended surface were not observed.

4. Conclusions

MIG welding under high pressure Ar atmosphere (0-6 MPa) has been studied by means of welding chamber designed to maintain controlled high pressure arc atmosphere. Effect of pressure on the arc voltage, welding current, arc shape and weld metal formation are studied. MIG welding process by constant arc voltage condition and constant arc length condition are compared.

The main results are summarized as follows.

1. With increasing of Ar pressure; (1) Arc become to constrictive, anode spot is concentrated at electrode tip then arc length become shorter. (2) Plural cathode spot and unstable arc are observed. Brightness of arc is increased. (3) A lot of spattered droplets and fine particles are produced.
2. As welding has been carried out using constant arc voltage condition; (1) Welding current increases with Ar pressure up to about 1 MPa and after it falls as the Ar pressure further increase (arc voltage 30V, W.M.R. 183 mm/sec). (2) Decreasing of heat input under high pressure is observed. (3) Wire melting rate decreases with Ar pressure up to about 0.5 ~ 0.6 MPa and then it increases slightly as the Ar pressure further raise (35V, 300A). (3) Crowned weld metals, narrow bead wide, weld metal which is not deep penetration are obtained.
3. As welding has been carried out using constant arc length condition; (1) Arc voltage is raised remarkably increasing with pressure from atmospheric pressure to 6 MPa. Arc voltage increase from about 38V to about 70V (arc length 5 mm, welding current 350A). (2) Increasing of heat input under high pressure is observed. (3) Crowned welds are not shown but flat welds are obtained. Bead wide, penetration depth are not affected by pressures. (4) Area of HAZ obtained at 6 MPa become more larger than that of 0 MPa. (5) Tensile and bending test results are satisfactory under condition of this study.
4. It has been estimated that constant arc length condition is good for MIG welding under high pressure arc atmosphere.

Table 2 Results of tension test

Ambient pressure P (MPa)	Tensile strength (MPa)	Location of fracture
0	459	Base metal
3	499	Base metal
3	503	Base metal
6	463	Base metal
6	485	Base metal

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