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In order to investigate effects of metal vapor on the plasma state in welding process, electron temperature in helium Gas Tungsten Arc (GTA) plasma during welding was measured by using the laser scattering method. Furthermore, density distributions of metal ions were also measured by using the spectroscopic analysis. Our results showed that plasma during welding consisted of two plasma regions, namely, pure helium plasma region and quasi-metal plasma region.

**Key Words**: Key Word, Key Word, Key Word, Key Word

**1. Introduction**

It is important in the welding process to investigate effects of metal vapor on arc plasma. Contamination of metal vapor to the arc plasma would change the plasma state of the arc. It means that arc plasma during welding is quite different from pure one.

Many researchers have tried a variety of investigations on metal contaminated arc plasma. Glickstein1) presented the result of spectroscopic measurements on a 100 A, 2mm arc length, argon arc with evaporation from heated alloy 600 plate. He showed that the arc temperature results determined with a stationary molten anode are similar to the results with a cooled anode. Etemadi and Pfender2) presented a result of spectroscopic measurements on a 150 A, 10 mm long, 800 Torr (1.07 102 KPa) argon arc with the evaporation from the molten copper. They found that the temperature decrease was 1000 K in a 1 mm region above the anode compared to the pure argon arc with water-cooled copper anode. Razafinimanana et al3) showed the result of spectroscopic measurements on a 90 A, 18 mm long, atmospheric argon arc with evaporation from copper anode. They also found that the temperature decrease was 2000 K near the anode. Furthermore, they showed a density of neutral copper atoms derived from the measurement of line spectrum intensity. Farmer et al4) showed the results of spectroscopic measurements on a 200 A, 5 mm long, atmospheric argon arc with evaporation from molten SUS304 which was inserted into copper anode. They reported that the metal vapor had no significant influence on the temperature distribution in the arc. They considered that the strong cathode jet in the case of 200 A of argon arc counteracted any tendency for metal vapor to flow or diffuse from anode to the arc. In computational investigations, Menart and Lin5) showed the results of numerical calculation on a 200 A, 10 mm long, atmospheric argon arc with copper evaporation. They predicted that the temperature decrease was 2000 K near the anode. Gonzalez et al calculated atmospheric argon arcs on a 200 or 300 A, 10 mm long with iron evaporation. Effects of metal vapor on transport and radiant properties of the arc were taken into account in their model. They also predicted that the temperature decrease was 2000 K near the anode.

From the above results, it can be considered that there is a problem in results. It is that both experimental and computational investigations have been carried out under the assumption of Local Thermodynamic Equilibrium (LTE) for the arc. For example, Farmer et al4) measured temperature distributions of the arc by using the Fowler-Milne method. This technique needs the accurate concentration of metal vapor under the assumption of LTE.

**2. Experimental procedure**

**2.1 Experimental set up for Thomson scattering**

In present work, helium gas was used as a shielding gas. This was due to two characteristics of helium gas. One is low arc pressure. This characteristic makes possible for metal vapor to arise more. Thus, it is applicable to investigate effect of metal vapor on the arc plasma. Another one is optically thin characteristic of helium. This characteristic prevents line spectrum absorption in plasma. Thus, this is applicable to observation of metal line spectrum.

**2.2 Experimental set up for spectroscopic measurement**

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Since the region in which electron temperature sharply decreases correspond to the blue luminous region as showed in Fig. 3, it can be supposed that metal vapor generated from the weld pool decreases the electron temperature of arc. Thus, metal vapor density distribution was derived from line spectrum intensity measurement. In the case of this measurement, experimental apparatus is similar to that of Thomson scattering except for the laser source. The detected line spectral intensity was decomposed spatially using Abel inversion method.

**3. Result and discussion**

Figure 1 shows a typical example of Thomson scattering profile. After fitting a theory profile, scattering parameter and Doppler shift width of electron term peak were acquired. From these data, electron temperature and electron density were derived.

Figure 3 shows the comparison between electron temperature for the pure helium arc with the water-cooled copper anode (left side) and that for the helium arc during welding (right side) under the same condition of 150 A in arc current and 5 mm in arc length. Figure 3 also shows characteristic appearances of the arc plasma in both cases. In the case of welding, there is a large, wide region of blue luminous plasma in the lower part of the arc. It is supposed that this blue luminous plasma appears to be mainly composed of metal vapor from the weld pool. In the region of 1 mm~3 mm from cathode tip, electron temperatures of both arcs are almost the same. On the other hand, in the region of 3 mm~4 mm from cathode tip, the electron temperature of GTA during welding decreases remarkably compared with the pure helium GTA plasma. Maximum difference of electron temperature reaches about 6000 K in the arc fringe.

Figure

# Fig. 1 Aaaaaa aaaaa aaaaa aaaaa aaaaa.

Figure 5 shows the result of ion density distributions of helium, iron, chromium, manganese and total metal in the arc axis, respectively. A hatched band is about 3.2 mm from the cathode. It is suitable for the boundary zone between the blue luminous plasma and another in Fig. 3. The density of helium ion reaches 2.3 1022 m-3 near the cathode and decreases with distance from the cathode. On the other hand, each ion of chromium, iron and manganese increases sharply between hatched band and anode. The ion of the highest density in the metal ions is chromium. The maximum reaches 1.0 1022 m-3 near the anode. Chromium, iron and manganese are in order of amount. This order should be related to the boiling point, ionization potential of each metal and the chemical compositions of SUS304 used in the present work. Figure 6 shows percentages of each ion density of total metals and helium to the whole sum of ions in the arc plasma. The hatched band at about 3.2 mm from the cathode tip represents the same meaning with in fig. 5. Figure 6 shows the plasma states of arc plasma during welding very clearly. Between cathode tip and hatched band, ions in the plasma almost consist of helium only. Between hatched band and anode, contrarily, ions almost consist of metals. Thus, it can be considered that the arc plasma during welding consists of two plasma regions, namely, pure helium plasma region and sort of like quasi-metal plasma region. This change of the plasma states obviously occurs at the hatched band as showed in Fig. 6. Thus, the quasi-metal plasma region is certainly in good agreement with the electron temperature decrease region in Fig.3. It means that metal vapor contamination significantly decreases the electron temperature in the arc plasma. It is insisted that decrease of electron temperature is occurred through two mechanisms when metal vapor contaminates arc plasma3). The first is an increase of electrical conductivity in the low temperature range. Abdelhakim et al showed that contamination of copper vapor to the arc led to much increase the electrical conductivity between 5000 K and 7000 K by calculating the collision cross sections. Jayaram and Ogawa also showed the same results. Increase of electrical conductivity makes an expansion of the conduction channel of electric current. It means that its current density becomes smaller. As a result electron temperature decreases owing to reduction of the ohmic heating. Thus, the arc voltage was measured. In the case of welding arc, measured arc voltage was 18.2 V. In the case of pure arc, that was 19.2 V. This result is consistent with the first mechanism. The second mechanism is an increase in the radiation emitted by the arc, which cause energy loss of the arc. Gleizes et al showed that metal vapor contamination to the arc led to increase in the energy loss by the radiation, especially at lower temperature. Maximum decrease of electron temperature is appeared in the low temperature region as showed in Fig. 3. This result consists with the second mechanism.

Figure

**Fig. 3** Ccccc ccccc ccccccccccc ccccccccc cccccc cccccc cccccc ccccc ccccc ccccc cccc ccccc ccccccccccc ccccccccc cccccc cccccc cccccc ccccc ccccc ccccc ccc.

**Fig. 2** Bbbbbb bbbbb bbbbb bbbbb bbbbb bbbbb bbbbb bbbbb bbbbb.

Figure

**4. Conclusions**

Electron temperature of helium GTA plasma during welding was measured by Thomson scattering method without LTE assumption. The results showed that the electron temperature decreased sharply near the anode, compared with that of pure helium plasma on the water cooled copper anode. The maximum decrease of electron temperature reached to 6000 K.

Furthermore, from the results of metal particle density distributions derived from line spectral intensity measurement, it was shown that the decrease of electron temperature was due to metal vapor contamination.

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**Reference**

1. J. J. Gonzalez, A. Gleizes, P. Proulx and M. Boulos: Mathematical modeling of a free-burning arc in the presence of metal vapor, J. Appl. Phys., 74-5 (1993), 3065-3070.
2. M. Boulos, P Fauchais and E Pfender: THERMAL PLASMA, Plenum Pub. Corp. (1994), 159.
3. H. Terasaki, M. Tanaka, H. Fujii and M. Ushio: Anode heat transfer in GTA welding, 6th inthernational conference on Trends in Welding Research, Atlanta (2002), 15-19
4. A. B. Murphy, A. J. D. Farmer and J. Haidar: Laser-scattering measurement of temperature profiles of a free-burning arc, Appl. Phys. Lett., 60-11 (1992), 1304-1306.
5. M. Tanaka and M. Ushio: Plasma state in free-burning argon arc and its effect on anode heat transfer, J. Phys. D Appl. Phys., 32 (1999), 1153-1162.