Dynamic Behavior Metal Vapor during Gas Tungsten Arc Welding*

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This study shows the time variation of temperature distribution and concentration distribution of metal vapor during gas tungsten arc welding. In this study, stationary gas tungsten arc welding of pure iron was conducted in helium as shielding gas. We investigated the influence of iron vapor on arc plasma and mechanism of iron vapor transportation from the weld pool into the arc plasma. We observed the arc plasma two-dimensionally with spectrometric method. We captured three different monochromatic images simultaneously by three monochromators with high speed video cameras. Thus, two inherence spectra of iron and also one inherence spectrum of helium in arc plasma were obtained. Using these spectra, plasma temperature distribution was obtained. In addition, concentration distribution of iron vapor was obtained by measuring electron density. It was concluded that plasma temperature decreased with increase of iron vapor concentration. Especially, the metal vapor concentration indicated the highest value near the base metal and the temperature around the weld pool decreased rapidly.

Key Words: Arc, Metal vapor, Temperature, Density

1. Introduction

Gas shielded arc welding has been diffusing throughout the industry as a welding method of high efficiency and high quality. Gas such as Ar, He, or Ar+H₂ mixture gas is used as a shielding gas for the purpose of shielding the arc plasma and the molten metal from the atmosphere. In order to obtain high-quality weld metal, it is important to understand the characteristics of arc plasma in various shielding gases. Additionally, it is known that metal vapor is generated from the molten pool when He or Ar+H₂ mixture gas is used for the shielding gas and the vapor is deeply involved with the change of plasma characteristics. The metal vapor is mixed into the arc plasma, as the result, the physical property such as electrical conductivity or radiative emission coefficient is changed. Through the change of arc plasma properties, the heat transfer phenomenon from the arc to the base metal is also influenced. Therefore, it is important to consider the behavior of metal vapor and influence of this metal vapor in arc plasma.

In this study, the time variation of temperature distribution of arc plasma and concentration distribution of metal vapor during gas tungsten arc welding were examined by the spectroscopic measurements.

2. Temperature measurement of GTA plasma

2.1 Experimental procedure

Arc plasma with metal vapor was observed two-dimensionally by using spectroscopic method. In the present experiment, the simultaneous three-wavelength spectroscopic measurement was attempted in order to obtain the plasma temperature with iron vapor. Therefore, the Fowler-Milne method and the two-line relative intensity method for the plasma region mainly consisted of shielding gas component, and the two-line relative intensity method for the region with metal vapor in the vicinity of molten pool, were adopted. The plasma in the vicinity of the molten pool is composed of a mixture with

![Fig.1 Schematic diagram of experimental setup](image)

Table 1 Wavelength of line spectrum

<table>
<thead>
<tr>
<th>Particle</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium</td>
<td>587.6 (HeI)</td>
</tr>
<tr>
<td>Iron</td>
<td>537.1 (FeI)</td>
</tr>
<tr>
<td>Iron</td>
<td>538.3 (FeI)</td>
</tr>
</tbody>
</table>
shielding gas and metal vapor so that the temperature of the iron vapor was measured by the two-line relative intensity method, which is not under the influence of plasma component.

Fig.1 shows the schematic diagram of the experimental device and the photograph is shown in Fig.2. A stationary tungsten gas arc was ignited on pure iron plate with the use of helium shielding gas. The plasma image was divided into three before Czerny-Turner type monochromator having a wavelength resolution of 0.6 nm, and each of those images was captured by high-speed cameras. The captured images were converted to temperature distributions by using the Fowler-Milne method and the two-line relative intensity method after Abel inversion.

Inherence spectrums used for this spectroscopic measurement are shown in Table 1. Iron spectrums of FeI: 537.1nm and FeI: 538.3nm were adopted in the region of iron vapor generation. In the region of helium plasma, the spectrum of helium atom (HeI: 587.6nm) was adopted. The plasma temperature distribution was obtained by superimposing the temperature distribution of the iron vapor on the temperature distribution of the shielding gas as shown in Fig.3.

In addition, concentration distribution of metal vapor was obtained by measuring electron density.

2.2 Basis of imaging spectroscopy

Intensity observed by the camera is determined by integration of radiant intensity from the arc along the line of sight as shown in Fig.4. The radiant intensity distribution calculated from the integrated with Abel inversion. The radiant intensity from the arc is theoretically calculated from the equation (1).

\[
I_{\text{arc}} = A \cdot h \nu \cdot N_0 \cdot \exp\left(-\frac{E_a}{kT}\right) \cdot \sum g_j \exp\left(-\frac{E_j}{kT}\right)
\]

Where \(A\) is transition probability, \(h\) is Plank constant and \(\nu\) is frequency, \(N_0\) is particle number density under the LTE assumption, \(g_j\) is statistical weight, \(E_a\) is level energy, \(T\) is temperature, \(k\) is Boltzmann constant. This equation (1) is based on spectroanalysis.

Fig.5(a) shows the relationship between temperature and intensity ratio at 587.6nm(He I). Fig.5 is required when using the fowlwe-milne method.

Fig.5(b) shows the relationship between temperature and intensity ratio at 537.1nm/538.3nm(FeI/FeI). Fig.6 is required when using the two-line relative intensity method.

Fig.6 Photograph of experimental setup
3. Result and discussion

Temperature distribution and iron vapor concentration (mole fraction) distribution are shown in Fig.6. The arc plasma at 0.1s and 4s after arc ignition are expressed. The left side of the figure is temperature distribution and right side is concentration distribution of iron vapor. The welding current and the arc length were set at 150 A and 3 mm, respectively. At 0.1s after arc ignition, iron vapor was not observed, and the temperature of plasma indicated over 22000K around central axis. The temperature nearby the molten pool also elevated to about 20000K. On the other hand, in the case of 4s after arc ignition, the iron vapor concentration indicated more than 20%, and the plasma temperature around the central axis decreased to19000K, additionally, that nearby molten pool decreased to 6500K. These results showed that the temperature of arc plasma decreased with the increase of metal vapor concentration. Especially, the iron vapor concentration was the highest nearby molten pool surface and the temperature near the molten pool decreased rapidly.

And Time variations of Temperature and density 0.3mm above a base metal is shown in Fig.7. These results also showed that the temperature of arc plasma decreased with the increase of metal vapor concentration.

When iron vapor is generated from molten pool, the electrical conductivity of arc plasma near the molten pool decreases, thus, the joule heating of plasma decreases. Additionally, it is expected that current density decreases with an increase in current pathway in the condition of iron vapor generation. As the result, plasma temperature at 4s after arc ignition assumed to be decreased.
4. Conclusions

In this study, the two-dimensional spectroscopic measurement of arc plasma was conducted, and the temperature distribution and concentration distribution of iron vapor were obtained. In the result, the temperature of arc decreased with the increase of iron vapor concentration. Especially, the temperature nearby molten pool, in which iron vapor concentration increases rapidly, decreased significantly.

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Reference