Memoirs of Fukui University of Technology, Vol. 29, Part 1, 1999

Influence of Shielding Gas Composition and ElectrodeVertex Angle on Surface Temperature of Weld Pool in Stainless Steel TIG Weld

by

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【SYNOPSIS】

When pure argon is used as the shielding gas for TIG weld of stainless steel, surface temperature of weld pool is the highest at the center of the weld pool, and from topological viewpoint,these results show distribution of palaboloid of revolution. On the other hand, when a small quantity of oxygen is mixed in argon, high temperature region at the center of the weld pool is spread in a direcion perpendicular to the bead, and the increase of vertex angle of electrode tend to promote these phenomena. The reason to form such high temperature region of weld pool seem to be related with equalization of plasma temperature due to high thermal conductivity of oxygen and equalization of current density in plasma fluxes caused by low ionization potential of oxygen.

I. INTRODUCTION

With remarkable progress of smelting technique in recent years, stainless steel of increasingly higher purity is now produced, and extensive improvement of product quality has been achieved. On the other hand, troubles such as lack of penetration frequently occur, and this gives serious influence on production efficiency as seen from social viewpoint. It is known that penetration in stainless steel as described above is closely relatd to fluid flow phenomenon in weld pool[(1)-(5)]. As the driving forces to govern the fluid flow in the weld pool, there are : (1) electromagnetic force ; (2) buoyancy ; (3) surface tension ; and (4) drag force of arc plasma. Among these driving forces, surface tension convection caused by surface tension as reported by Heiple et al.[(6)-(8)] (also called Marangoni convection) is considered as the most prominent factor. The results of the study of the present authers[(9)-(11)] are also mostry consistent with the results repoted by Heiple et al. However, since surface tension is also a function of temperature, the driving forces are influenced by temperature of weld pool, in particular, by surface temperature of weld pool. When surface active elements such as oxygen are present, the surface tension temperature gradient is changed. For example, when argon gas mixed with oxygen is used as the shielding gas, arc characteristics and weld pool surface temperature are influenced by dissociation energy of oxygen in addition to temperature coefficient, and fluid flow phenomenon may also be subject to changes. Further, it is considered that vertex angle of electrode may exert influence on arc characteristics. It may influence on weld pool

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convection, and hence,on penetration due to contribution to surface temperature. Fig.1 shows the penetration in view of a_1/a_2 ratio [10], i.e.characteristic value of d/W ratio, which is an index of penetration when bead-on-plate welding is performed on SUS 304 at vertex angle of 30°～120° and mixed gas containing oxygen up to 3000 ppm in argon is used as the shielding gas. From Fig.1, it is evident that, when oxygen is blended in argon, a_1/a_2 ratio rapidly increases as oxygen concentration is increased to 1000 ppm or more, and that penetration is improved, while the increase of vertex angle tends to inhibit penetration.

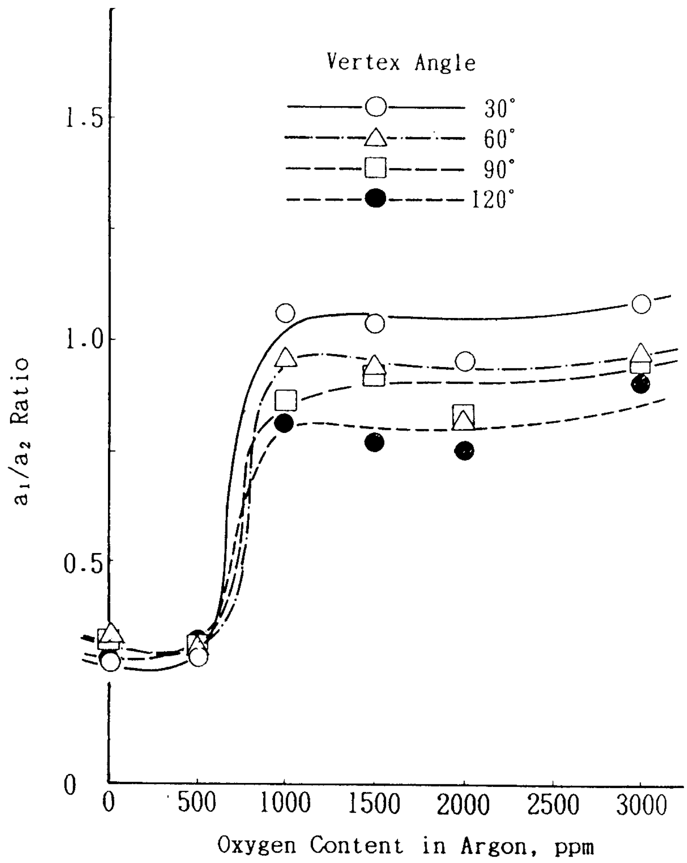

Fig.1 Relation between (a_1/a_2)Ratio and Oxygen Content in Argon as Shielding Gas of SUS 304 TIG Weld, welded with various Vertex Angle of Electrode.

As described above, penetration of stainless steel is apparently influenced by oxygen concentration in the shielding gas or by vertex angle, and this suggests that it is closely related with surface fluid flow of weld pool,and hence,with surface temperature of weld pool. In this respect, we have tried, in the preset study, to determine surface temperature of weld pool using radiation thermometer and to evaluate fluid flow phenomenon as well as the influence of oxygen concentration in the shielding gas and vertex angle on the surface temperature.

Ⅱ. EXPERIMENTAL PROCEDURE

In the present study, commercially available SUS 304 (3.0 mm in thickness) was used as specimen material. As electrode,thoriated tungsten with vertex angle of 30°,60°,90° and 120° and 2.4 mm in diameter was used. At the welding speed of 20 cm/min. in DCEN, bead-on-plate welding was performed in the shielding gas with oxygen concentration of 0%, 500ppm, 1000 ppm and 2000 ppm.

At the method to determine temperature of the surface of weld pool,optical spectral radiometric laser reflectance method of Kraus et al. [12]-[14] or a method using infrared, single color or two-color radiation thermometer [15] are known for the cases of high temperature such as weld pool. Because it is necessary to determine high temperature within a limited small region such as weld pool in the present study, a single color radiation thermometer(TR-630A;Minolta) to determine high temperatur in very small region within 0.4 mm in diameter was used. For the temperature measurement[I],two radiation thermometer was used. As shown in Fig.2 from the front side of weld pool, forcus of the thermometers was fixed to the center of weld pool immediately under the arc and in marginal region of 0.4 mm in diameter at 0.4mm inside from weld fusion line,and temperature change during welding was determined and recorded using a data collecting system(NR-250;Keyence).

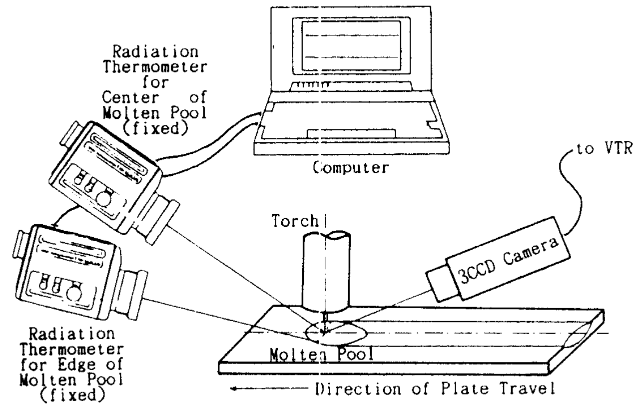

Fig.2 Schematic Illustration for Temperature Measurement Method of TIG weld Molten Pool Surface by Radiation Thermometer with fixed Forcus.

On the other hand, in the temperature measurement [Ⅱ], as shown in Fig.3, one of the thermometers was set perpendicularly to the welding direction through the center of weld pool from the front side of weld pool and the other thermometer was set in parallel to the welding direction and was oscillated at a constant speed in the weld pool, and temperature distribution in the weld pool was determined and recorded.

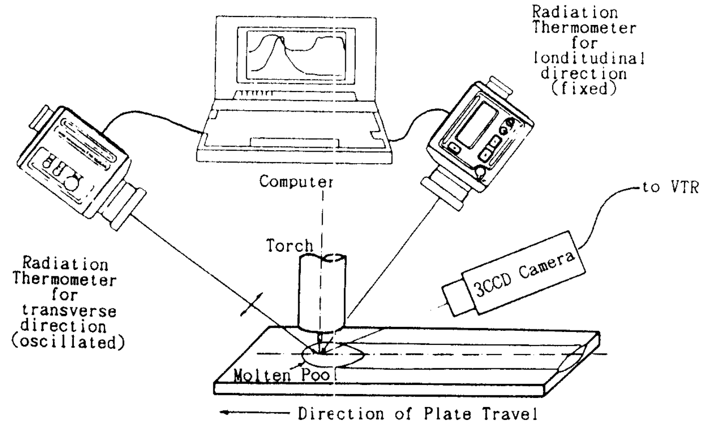

Fig.3 Schematic Illustration for oscillated Temperature Measurement Method of TIG Welded Molten Pool Surface by Radiation Thermometer.

Further,at the same time with the temperature measurement as described above,fluid flow on the surface of the weld pool was observed via ZrO_2 tracer using 3 CCD cameras(Stenning), and the results were compared with the result of temperature measurement.

Ⅲ. RESULTS OF EXPERIMENT AND DISCUSSION

Fig.4 shows the results of temperature measured immediately under the arc of weld pool and in marginal region of weld fusion line as determined by the method of the temperature measurement[Ⅰ] shown in Fig.2 using oxygen concentration in the shielding gas as parameter. In this measuring method, temperature measurement data is represented by two continuous parallel lines showing temperature at the center and at marginal region of the weld pool. Fig.4 shows the results obtained by plotting the temperature represented by these parallel lines. As shown in Fig.4, the surface temperature at the center of the weld pool is within the range of 2400 K to 2500 K and exhibits almost no change even when oxygen concentration in the shielding gas is increased. However, when vertex angle is increased, temperature tends to slightly decrease.

On the other hand, when the shielding gas is pure argon and vertex angle is an acute angle, the temperature on the marginal region is about 1750 K, which is closer to the melting point(1743 K) of SUS 304, while temperature is raised with the increase of oxygen concentration in the shielding gas.

This tendency becomes more remarkable when vertex angle is increased. When vertex angle is 120° and the mixed gas contains oxygen of 2000 ppm, temperature immediately under the arc on the surface of the weld pool were almost consistent with temperature on the marginal region (2350 K at the center of weld pool and 2326 K at the marginal region). Fig.5 shows temperature distribution pattern through the center of weld pool and in a direction in parallel to the welding direction as determined in the temperature measurement [II] under each measuring condition. Fig.6 shows temperature distribution pattern in a direction perpendicular to the welding direction under each measuring condition. As it is evident from Fig.5 and Fig.6, in the temperature distribution through the center of weld pool surface and in a direction in parallel to the welding direction, the influence of oxygen concentration in the shielding gas or vertex angle is not so conspicuous, while, in a lateral direction of the weld pool perpendicular to the welding direction, there is a tendency to form isothermal region when oxygen concentration in the shielding gas is increased, and this shows good coincidence with the results shown in Fig.4.

In Fig.7 and Fig.8, surface

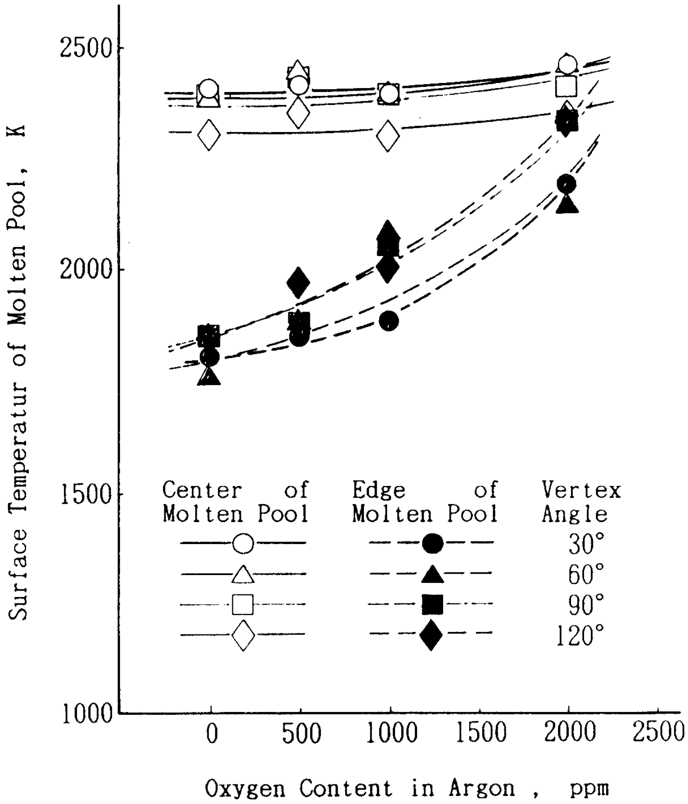

Fig.4 Effect of Oxygen Content in Argon Gas on Surface Temperature of SUS 304 Weld Pool, welded by TIG Process.

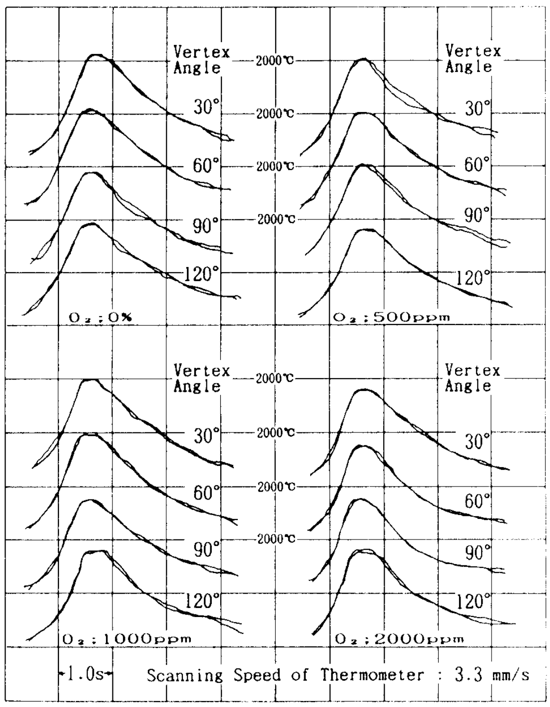

Fig.5 Temperature Profile of Weld Pool Surface, measured right under the Arc, longitudinaly.

temperature of weld pool is given from topological viewpoint based on the results of temperature measurement on the weld pool surface in case pure argon or mixed gas containing oxygen of 2000 ppm are used in the shielding gas among the data shown in Fig.5 and Fig.6. With regard to the temperature distribution on the weld pool surface of stainless steel TIG weld, the results reported so far [9]-[11] have been obtained using pure argon in the shielding gas. From topological viewpoint, these results show distribution of paraboloid of revolution approximately similar to the distribution shown in Fig.7.

However, when the gas with low ionization potential such as oxygen is blended in argon, isothermal region as shown in Fig.8 may be formed in high temperature region at the center.

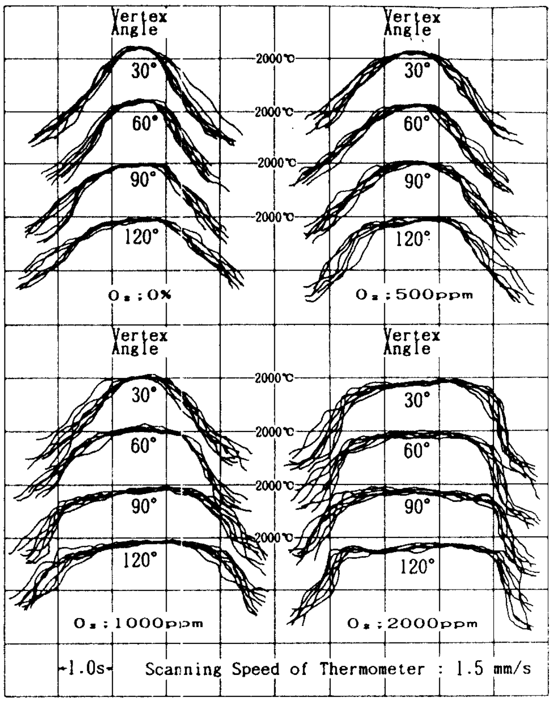

Fig.6 Temperature Profile of Weld Pool Surface, measured on right under the Arc, transversely.

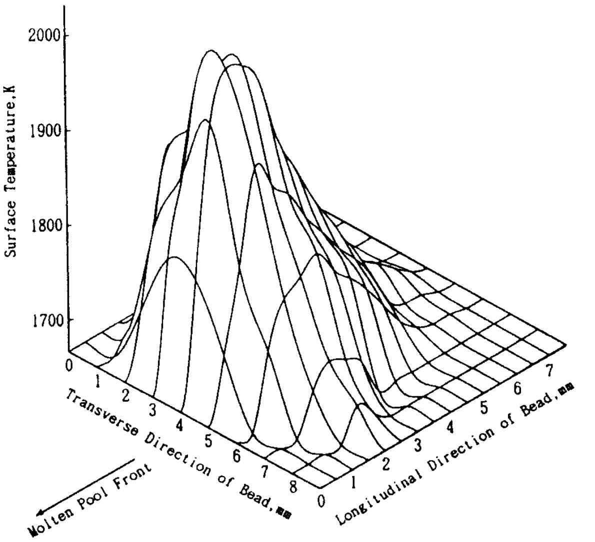

Fig.7 An Example of Weld Pool Surface Temperature Topology of SUS 304, welded in Pure Argon as Shielding Gas with Electrode Vertex Angle of 30°.

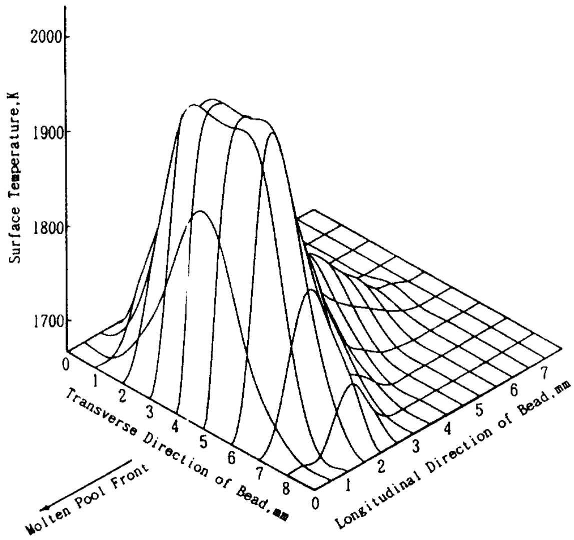

Fig.8 An Example of Weld Pool Surface Temperature Topology of SUS 304, welded in Argon Gas containing 2000 ppm Oxygen as Shielding Gas with Electrode Vertex Angle of 120°.

One of the reasons to form such isothermal region may be the increase of thermal conductivity in the shielding gas or arc plasma. Specifically, thermal conductivity and specific heat of oxygen are about twice as much as those of argon. For this reason, the temperature in arc plasma is more equalized than the case of pure argon. Current density in the arc plasma is also equalized because ionization potential is low (as a result, temperature of arc is somewhat reduced). To the weld pool, heat is supplied from a heat source, which is a facial heat source rather than a point heat source. In consequence, broader isothermal region may have been formed. On the other hand,when vertex angle is increased,the shape of arc is turned to temple bell-like shape rather than the shape similar to inverted wine cup, and this may exert an effect to equalize temperature distribution in the plasma and may promote formation of isothermal region. When vertex angleis increased, arc plasma column is narrowed down. This has been reported by S.Y.Lee et al.[16] who studied current density distribution of vertex angle. Their results suggest that arc force is also in creased.

When oxygen is blended in argon, tracer particle(ZrO_2) in the weld pool tend to be concentrated at the center rather than on marginal region of the weld pool as seen in the rsults of observation by special CCD camera on the weld pool surface. Surface tension temperature gradient is apparentry “positive”, and it appears that temperature dependency of surface tension caused by oxygen is not turned to “negative”by the surface temperature. In contrast, in case of pure argon, there is a tendency that the particles are concentrated toward the marginal region and this suggest that the surface tension temperature gradient is “negative”.

The results of measurement of surface temperature of weld pool on stainless steel TIG weld as described above are correlated well with the influence of oxygen mixed gas or of vertex angle on the penetration as shown in Fig.1.

Ⅳ. SUMMARY AND CONCLUSION

Evaluation was made on the influence of oxygen concentration in argon shielding gas and vertex angle of electrode on the surface temperature of weld pool of stainless steel TIG weld. The results of the study may be summarized as follows:

(1) When pure argon is used as the shielding gas, surface temperature of weld pool is the highest at the center of the weld pool and it is closer to the melting point of the base material in the marginal region. When oxygen is blended in argon, high temperatur region at the center of the weld pool is spread in a direction perpendicular to the bead with the increase of oxygen concentration. Thus, temperature difference between the marginal region and the center of the weld pool is decreased, and a broader isothermal region is formed.

(2) The increase of vetex angle of electrode tends to promote formation of isothermal region.

(3) The decrease of temperature difference between the center and the marginal region of the weld pool as shown in the argon gas mixed with oxygen seems to be related with equalization of plasma temperature due to high thermal conductivity of oxygen and with equalization of current density in plasma fluxes caused by low ionization potential of oxygen.

(4) The results of observation of tracer particles using CCD camera suggest that surface tension temperature gradient in the weld pool welded in shielding gas blended with oxygen is “positive”, on the other hand, the temperature gradient in pure argon is “negative”.

(5) The results of measurement of surface temperature of weld pool caused by the difference of oxygen concentration in argon shielding gas or by the difference of vertex angle of electrode are correlated with the penetration phenomenon.

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(Received December 3 , 1998)