"Effect of Steel Types and Oxygen in Argon Shielding Gas on the Penetration of stainless Steel TIG Welds"

by

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[ABSTRACT]

Evaluation was made on the effect of oxygen adding argon gas on penetration of Cr type(SUS 430) and Cr-Ni type (SUS 304) stainless steels. It was found that penetration was improved with the increase of oxygen concentration for SUS 304 stainless steel. While no remarkable improve was observed for SUS430, and melting efficiency was also low. The same trend was found in (P) value, which takes fused area into consideration. Such difference in the effect to improve penetration may partially due to the difference of thermal conductivity between these types of steel. Another factor may be the difference of equilibrium oxygen concentration of chromium oxide which is generated on the surface of molten pool during welding.

I. INTRODUCTION

It is well known that penetration phenomenon in TIG weld of stainless steel is closely related with fluid flow in the molten pool, and that driving forces to controle the fluid flow in the molten pool are derived from : (1) electromqgnetic force; (2) buoyancy; (3) surface tension; and (4) drag force of arc plasma. It is reported that surface tension convectin (so called "Marangoni convection") originated from the gradient of surface tension is the most prominent governing factor among these driving forces, as reported by Heiple et al[1]. The result obtained by one of the present arthors has agreed with the results ofHeiple et al. to considerable extent[2]. On the other hand, it is known that surface tension has an efect to rise a_1/a_2 ratio (or d/W ratio, which is an index to show the shape of the fused zone, d;depth, W;width,) when small quantity of oxygen or sulfur (known as surface active element n molten iron)is added. This phenomenon explained by the fact that temperature coefficient of surfaceten sion ,serving a driving force of fluid flow in molten pool, is turned from "negative" to "positive".

The present authors have taken special attention to oxygen as active element to improve the penetration of SUS 304 steel and developed an oxide film method to add small quantity of oxygen to the molten pool and also a method to apply the oxygen-mixed argon gas as shielding gas. It was confirmed that both methods provided remarkable effects[3][4]. However, it is not yet elucidated whether the effects to improve penetration by small quantity of oxygen as observed in SUS 304 steel is also found or not in the types of stainless steel other than SUS 304.

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About 60 types of stainless steel specifications are listed in JIS (Japan Industrial Standards) including Cr type and Cr-Ni type stainless steel in category of stainless steel plate or strip. These different types of stainless steel are not only different in nominal composition of Cr, Ni, etc., but also different in physical properties such as melting point, thermal conductivity or specific heat, which are closely related with penetration phenomenon, and transport.

In this respect, evaluation was made on SUS 430 steel containing only 18%Cr as a different type of stainless steel from SUS 304, in composition, micro-structure and in other physical properties. The effects of oxygen concentration in shielding gas onthe penetration were assessed under different electrode vertx angles, and the compared with the results obtained for SUS 304 stainless steel.

Ⅱ.EXPERIMENTAL PROCEDURE

SUS 430 and SUS 304 materials used in the present study were commercial available cold-rolled and annealed products(2B finishing ; 3.0 mm in thickness).

Chemical composition of these materials are summarized in Table 1. From these

Table 1 Chemical composition of materials used (mass %)

steel	C	Si	Mn	P	S	Cr	Ni	N,ppm	O,ppm
SUS 304	0.060	0.61	1.01	0.029	0.0010	18.24	8.19	0.04	45.46
SUS 430	0.062	0.56	0.30	0.027	0.0015	16.10	0.12	0.01	17.18

materials, a number of small pieces each in size of 3.0×30×180 mm were cut off and these were used as test pieces.

On the central portion in longitudinal direction of each of these test pieces, bead-on-plate welding was performed using TIG method (DCEN) under the following conditions: arc length : 2.0 mm, welding speed : 40 cm/min, heat input : 0.5~3.0 kJ/s, electrode vertex angles : 30°,60°,90°,and 120°. As shielding gas, in addition to pure argon, mixed argons with oxygen at 500,1000,1500,2000 and 3000 ppm were used.

After welding, each test pieces were cut off at several points perpendicularly to beads. After macro etching, the section was photographed using macro-zoom camera with magnification of×10. From the photographs of the sections, penetration depth (d) and bead width (W) were measured, and regression equation of (d) or (W) and heat input (Q) was obtained by least square method. The value of (d) or (W) can be expressed as linear equation : $d = a_1Q \pm b_1$ or $W = a_2Q \pm b_2$. Therefore, d/W ratio, which is an index of shape of penetration,can be given as a fractional function of:$(d/W)=(a_1Q\pm b_1)/(a_2Q\pm b_2)$. This d/W ratio is a function of Q. In this respect, it is necessary to identify the value of Q for the assessment, and this is inconvenient for the purpose of comparison. To overcome this problem, we used characteristic value in the present study, which is given by regression coefficient ratio of $\lim_{Q\to\infty}(d/W)$ or $d/dQ\cdot(d/W)\cdot = (a_1/a_2)$ because limit value of (d/Q) and (W/Q) per unit heat input are give as: $\lim_{Q\to\infty}(d/Q)$ or $(dd/dQ) = a_1$, and $\lim_{Q\to\infty}(W/Q)$ or $(dW/dQ) = a_2$.

Using the value of a_1/a_2 ratio as used here, penetration depth of bead can be indicated, but the extent of melting, i.e. fused area, can not be evaluated. If fused area is extremely different even if a_1/a_2 ratio is the same, it is desirable to evaluate as different type of penetrations. Therefore, in the present study, fused area (S_B) was determined on the same section where (d) and (W) were determined, and the relation between the melting area (S_B) and heat input (Q) was obtained. The relation between S_B and Q thus obtained is given in the form of exponential function as $(S_B) = Q^n \cdot e^{\pm C}$. Similarly to (d/W) ratio, this is a function of Q. Taking logarithmic values on both sides in the above equation, the value of ln (S_B/Q), i.e. the value of ln (S_B) per unit heat input when $Q \to \infty$ is obtained as: $\lim_{Q \to \infty} \ln (S_B/Q)$ or $d/dQ(\ln S_B) = n$. Thus, the value of S_B can be expressed by the value of n. Therefore, the product of this value of n and (a_1/a_2) ratio as described above [i.e. $(a_1/a_2) \times n$] also serves as an index to express the penetration. The value of (P) may be defined as a more adequate and reasonable index of penetration because fused area is included into consideration.

Finally, in the present study, the penetration was evaluated by the value of (P), in addition to (a_1/a_2) ratio as given previousely.

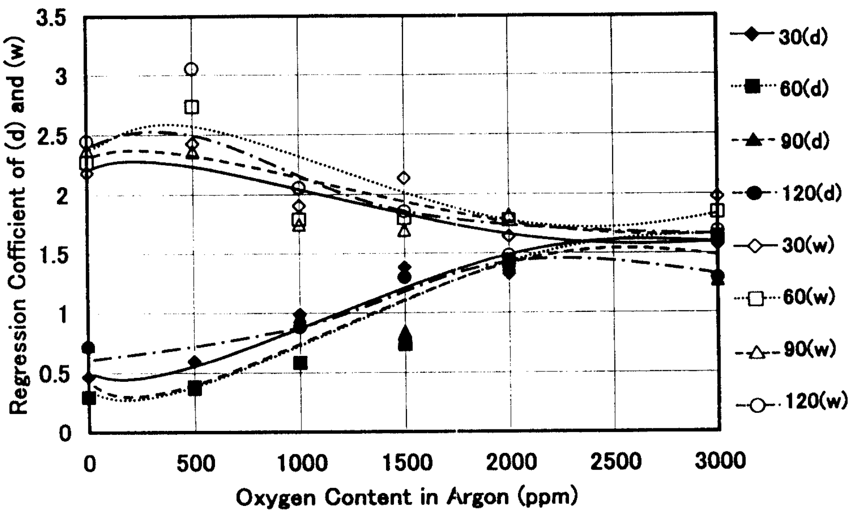

Fig.1 Effect of Oxygen Content in Argon as Shielding Gas on Regression Coefficient of (d) and (W) Regression Line of SUS 304 Stainless Steel TIG Welds.

Ⅲ. EXPERIMENTAL RESULTS AND DISCUSSION

Coefficient of (d) and (W) in regression equation was determined from the relation between heat input (Q) and (d) as well as (W) of stainless steel materials, SUS 304 and 430. The relation between the regression coefficient and concentration of oxygen in shielding gas is shown in Fig.1 and 2 for each vertex angle. As it is

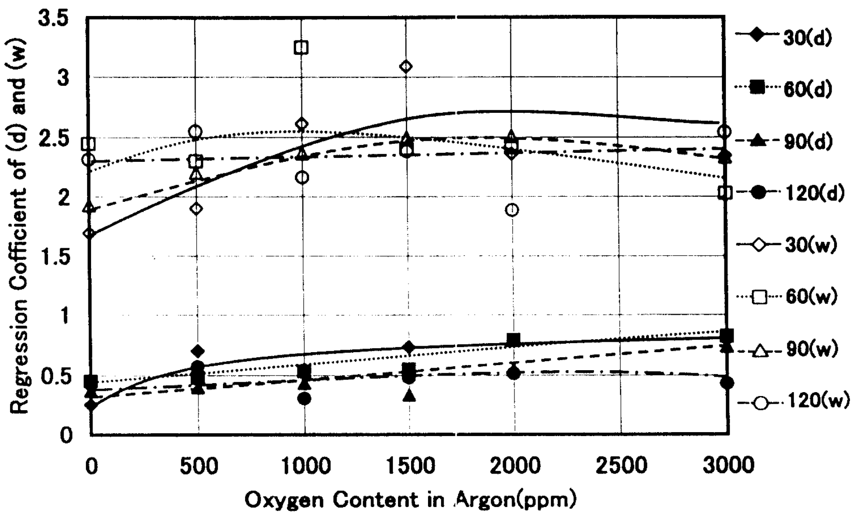

Fig.2 Effect of Oxygen Content in Argon as Shielding Gas on Regression Coefficient of (d) and (W) Regression Line of SUS 430 Stainless Steel TIG Welds.

evident from the both Figures, the value of (d) of SUS 304 increases with the increase of oxygen concentration. On the contrary, the value of (W) tend to decrease.

The value of (W) of SUS 430 shows slight increase of oxygen concentration, but the change of (d) is very small, and this reveals that penetration in the direction of plate thickness is relatively shallow, even if oxygen concentration is changed. Therefore, characteristic value of (d/W) ratio, which serves as an index of penetration expressed by the ratio of (d) to (W), i.e. the (a_1/a_2) ratio at various oxygen concentration, is as shown in Fig.3 and 4 for each vertex angle. That is, in case of SUS 304, the (a_1/a_2) ratio rapidly increase when oxygen concentration exceeds 1000 ppm and penetration becomes deeper. In case of SUS 430, slight increase in depth is observed when oxygen concentration exceeds 2000 ppm or more. Thus, there is considerable difference in the effect to change penetration by oxygen adding to argon gas for these two type of stainless steel.

When the effect of vertex angle on (a_1/a_2) ratio is observed in case of SUS 304, there is a tendency that (a_1/a_2) ratio is higher when vertex angle is smaller(i.e.sharp tip geometry) in low oxygen concentration region. On the other hand, (a_1/a_2) ratio tend to be higher when vertex angle is larger (i.e.blunt tip geometry) in high oxygen concentration region. In case of SUS 430, however, there is no distinct tendency.

These results suggest that the value of (P) used as an index of penetration indicates similar trend, and good agreement was seen between materials (Fig.5 and 6).

As described above, when oxygen-mixed argon is used as shielding gas, the effect to

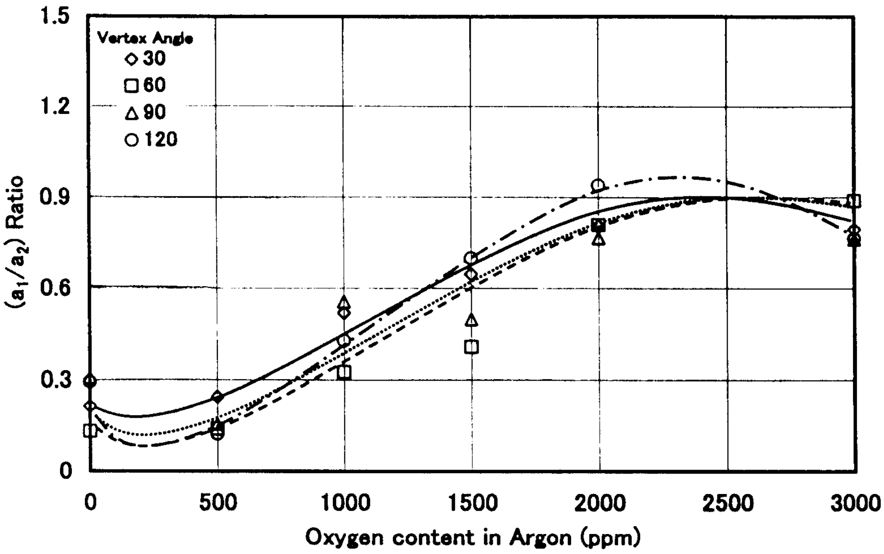

Fig.3 Effect of Oxygen Content in Argon Shielding Gas on the (a_1/a_2) Ratio for SUS 304 Stainless Steel TIG Welds.

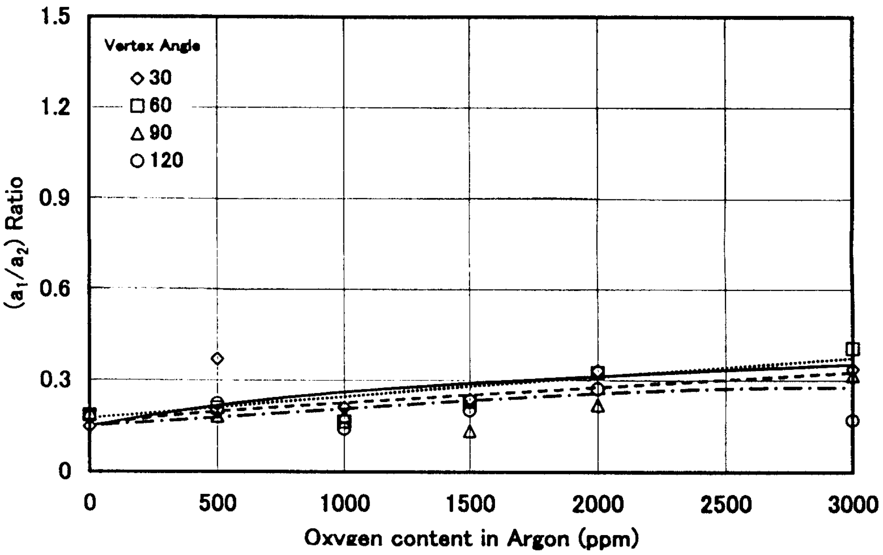

Fig.4 Effect of Oxygen Content in Argon Shielding Gas on the (a_1/a_2) Ratio for SUS 430 Stainless Steel TIG Welds.

make deep penetration was clearly observed in case oxygen concentration was about 1000 ppm or more in SUS 304, while no effect was indicated in SUS 430. One of the reasons of this difference may be the difference in thermal conductivities and specific heats between SUS 304 and 430 as previously described in the introduction. Table 2 shows comparison of physical properties of SUS 304,430 and carbon steel. As it is seen in Table 2, thermal conductivity of SUS 430 is about 1/2 of carbon steel, but thermal conductivity of SUS 304 is about 1/3 of carbon steel, and the former is higher than case of SUS 304. In general, maximum attainable

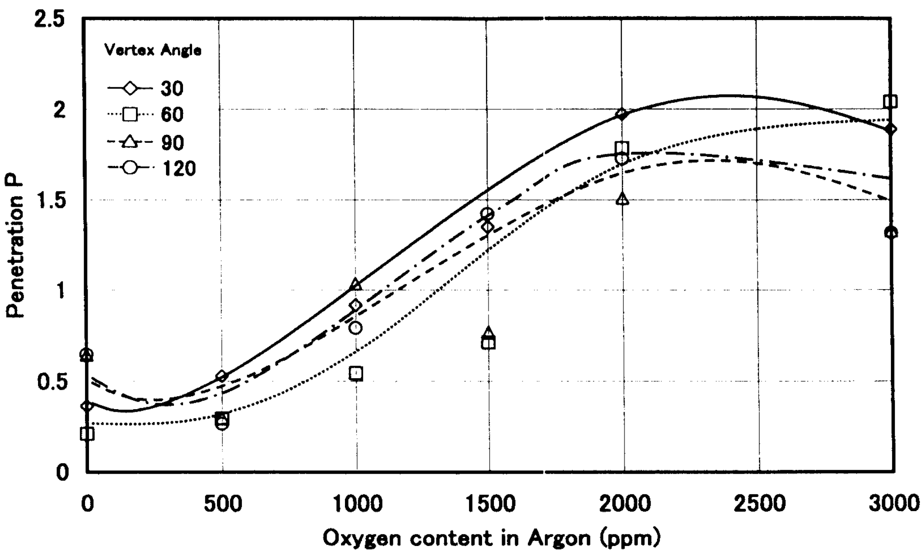

Fig.5 Relation between Oxygen Content in Argon Gas and Penetration Index expressed by (P) Value of SUS 304 Stainless Steel.

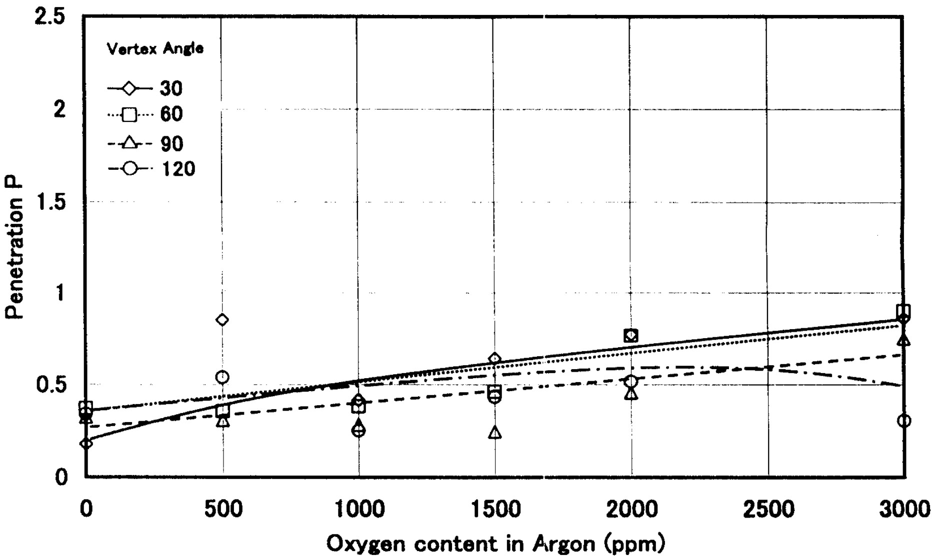

Fig.6 Relation between Oxygen Content in Argon Gas and Penetration Index expressed by (P) Value of SUS 430 Stainless Steel.

Table 2 Some physical properties of SUS 304 and SUS 430 stainless stel

Physical property	SUS 304	SUS 430	Carbon steel
Density (gr/cm^3)	7.93	7.75	7.85
Specific heat (J/kg·℃)	502	419	460
Thermal conductivity ($kcal/cm^2/sec/℃/cm$)	14	22	50
Thermal Difusivity (cm^2/sec)	3~5	3~4	5

temperatur(θ_{max}) from the weld line to a point at a distance "y" perpendiculaly to the weld line is given from 3-dimentional thermal conduction theory[5] of plate based on a moving heat source as follows:

$$\theta_{max} - \theta_0 \fallingdotseq Q/2Y\lambda h\sqrt{2\pi e} \quad \cdots(1)$$

where θ_0 is initial temperature of plate (℃),Y is vy/2k, v is welding speed (cm/min), k is thermal diffusivity (cm^2/sec), h is plate thickness (cm), and λ is thermal conductivity (kcal/cm^2/sec/℃/cm). From the above equation, toe line distance "y" (distance where θ_{max} reaches melting point) is given by :

$$y \fallingdotseq k/1.43\lambda h(\theta_{max} - \theta_0)\cdot(Q/v) \quad \cdots(2)$$

According to the equation (2), when the value of λ increases, the value of "y" is decreased. That is, the distance from heat source is reduced, and this leads to the decrease of penetration. Therefore, even when SUS 430 is welded with the same heat input, its penetration depth is shallower than that of SUS 304. However, it is assumed in thermal conduction theory that heat conduction is spread concentrically from heat source, and it is not possible to indicate the relation with bead width, which serves as an index of penetration. In fact, as it is evident from Fig. 2, bead width (W) of SUS 430 is far greater than (d). As a result, (a_1/a_2) ratio, serving as an index of penetration, is extremely lower in SUS 430 compared with SUS 304. As explained already, when active element such as oxygen is present on the surface of molten pool, temperature coefficient of surface tension, which gives driving force of surface convection, is converted to "positive", and accordingly it promotes heat transport in the direction of plate thickness and extremly increases penetration depth. This phenomenon was clearly observed in SUS 304. This difference may be attributed to the influence of equilibrium oxygen concentration and chromium in the molten pool of Cr type stainless steel and Cr-Ni type stainless steel. Namely, in case chromium oxide is present at the surface of molten pool in the oxygen-mixed argon gas atomosphere, equlibrium reaction[6] of Fe-Cr-O system is given as follows:

$$2\,Cr + 3\,O = Cr_2O_3\ (s) \quad \cdots(3)$$

Equliblium oxygen concentration in this case at 1600 ℃ is about 0.03%[7] in case of SUS 430, while it is about 0.1%[8] in case of SUS 304 which contains Ni. Therefore, in SUS 430, when very small quantity of oxygen is mixed, the reaction is immediately transferred toward the right side in the above equation,and the generated chromium oxide covers the whole surface of the molten pool.

The chromium oxide has high melting point and is firm. The formation of such a oxide film hinders heat transport in the direction of plate thickness and also obstructs surface tension fluid flow on the surface of the molten pool. As a rsult, this may extensively decrease the penetration. On the other hand, in case of SUS 304, the presence of small quantity of oxygen sufficiently exerts action as active element, converting surface tension temperature coefficient to "positive" and improveing the penetration. However, when oxygen concentration in argon reaches a level as high as equilibrium concentration, the reaction advances toward the right side of the equation (3). Accordingly, fluid flow in the molten pool is suppressed, and the (a_1/a_2) ratio is rduced. This may be the reason why the (a_1/a_2) ratio in SUS 304 was decreased when oxygen concentration was near 3000 ppm, and the difference of penetration shown in oxygen-mixed argon gas between SUS 304 and SUS 430 may also be attributed to this. As deescribed above,penetration depth of SUS 430 is considerably smaller compared to that of SUS 304. In this respect, in order to give the same fuse volume to SUS 430 as that of SUS 304, it is necessary to give more higher heat input than in SUS 304. Heat input(kJ/s) necessary for giving melting efficiency (Z_m) of 30% to TIG weld was calculated using the equation of Jackson[9] with the value of (S_B) observed in this study. Fig.7 shows the heat input (kJ/s) calculated for various oxygen concentration. When oxygen concentrationis becomes higher, heat input tends to decrease for these two types of steels, and it is demonstrated that SUS 430 requires about 20% higher heat input more than for SUS 304. These results agree well with the welding condition those selected when these two types of steel are welded by TIG process.

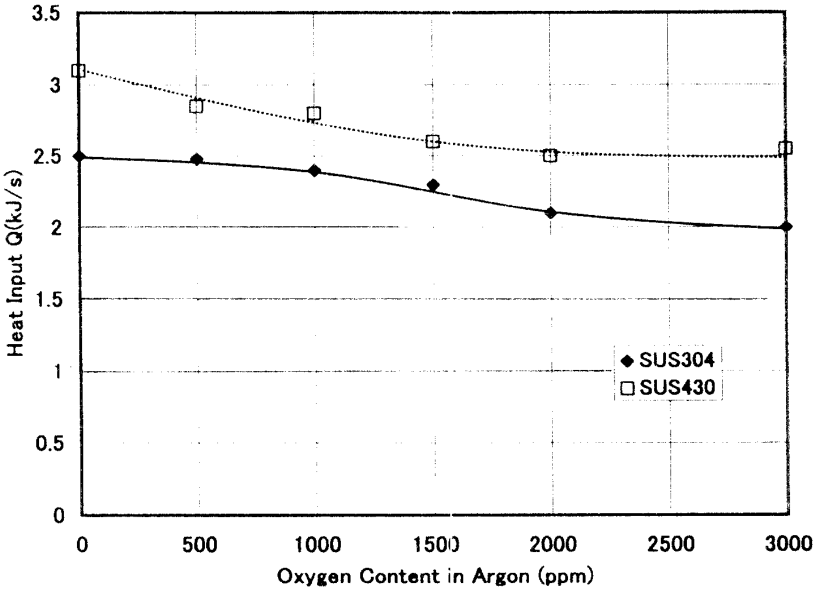

Fig.7 Heat Input necessary to give Meltion Efficiency of 30% of SUS 304 and 430 Stainless Steel TIG Welds, welded in Argon blended small Quantity of Oxygen as Shielding Gas.

Ⅳ. CONCLUSION

SUS 304 and 430 were selected as typical Cr type and Cr-Ni type stainless steels. Experimental evaluations were made on the effect of oxygen-mixed argon gas and on the electrode vertex angleon in respect to the penetration depth in TIG welds for these two types of stainless steel. The rsults obtained in the study are summarized as follows:

(1) Oxygen-mixed argon gas extensively improves the penetration depth of SUS 304 steel when oxygen concentration is about 1000 ppm or more. The effect of vertex angle on the penetration is not distinct, while there is a tendency that the effect to improve penetration is higher when vertex angle is sharp in case oxygen concentration is low and when it is obtuse in case oxygen concentration is high.

(2) The effect of oxygen adding to argon gas on the penetration of SUS 430 is low, and the improvement of penetration depth could not take place as the effect of oxygen adding.

(3) The effect of oxygen-mixed argon gas and vertex angle of electrode on the penetration of SUS 304 and 430 also showed similar tendency when the value (P) was used as an index for penetration.

(4) The difference of penetration between SUS 304 and 430 caused by oxygen-mixed argon gas may be partially attributed to the difference of thermal conductivity between

these two types of materials. Another major factor may be the difference of equilibrium oxygen concentration with respect to chromium oxide,which is generated on the molten pool during welding. The molten pool of SUS 430, which has lower equilibrium oxygen concentration, is covered with chromium oxide in earlier stage of melting, and this may be the reason why penetration was also low in oxygen-mixed argon gas.

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