Influence of the Oxide Film on the Weld Penetration Phenomena of Stainless Steel

Kiichi SAITO*

ABSTRACT

With the purpose of improving penetration property of TIG welds of stainles steel, evaluation was made on the possibility to oxidize the stainless steel surface and to dope oxygen on the weld metal from oxide film. As a result, (d/W) ratio, which an index of penetration property, apparently increased by giving oxide film on stainless steel surface, and penetration could be remarkably improved. The effect of the oxide film to improve penetration property may be attributable to the fact that the oxide film is decomposed by arc heat in high temperature portion of molten pool, thereby increasing oxygen concentration of that region, and that this caused "positive" surface tension temperature gradient and Marangoni convection from central portion of the molten pool to the bottom portion thereof occurred.

INTRODUCTION

With remarkable advance in refining technique to produce high purity stainless steel such as secondary refining process in recent years, high purity stainless steel, e.g. the products containing Oxygen$<$30 ppm, Carbon$<$10 ppm, Nitrogen$<$30 ppm, Sulfur$<$10 ppm, and Phosphorus$<$100 ppm, are now routinely produced as commercial products. On the other hand, however, the production technique to produce such high purity stainless steel products decreases the ratio (d/W) of penetration depth (d) to bead width (W), which is an index of penetration property during TIG welding, and the cases with poor penetration are often reported. At the same time, troubles in welding related to lack of penetration are also increasing. Recently, P.Burgardt et al.[(1)] and C.R.Heiple et al.[(2)(3)] suggested that the difference of (d/W) ratio may be related to the quantities of active impure elements such as Oxygen and Sulfure contained in base metal, and the decrease of such elements may tend to reduce (d/W) ratio. The purpose of the present study was to evaluate the possibility to improve penetration property by increasing (d/W) ratio in TIG welding of stainless steel produced in high purity by providing oxide film on the weld zone and by doping the weld metal with oxygen during welding.

EXPERIMENTAL PROCEDURE

The stainless steel used in the present study was a commercially available SUS 304

* Faculty of Mechanical Engineering

sheet (thickness : 3.0 mm) with the following contents : C:0.06%, Si:0.29%,Mn: 1.14%, P:0.023%, S:0.002%, Cr:18.13%, Ni: 8.52%,and O:0.0035%. After a number of test pieces in size of 50×250 mm were prepared from the sheet material,oxidizing treatment was performed in air at 1273 K for 0 sec.(as-received), 300 sec., 600 sec., 900 sec., and 1200 sec.respectively. Then,bead-on-plate welding by TIG process was carried out under the following conditions : welding current; 150 - 250 A (DC.SP), welding voltage ; 12.7 to 14.2 V, welding speed ; 13.0 cm/min., and heat input 8.8 to 16.4 kJ/cm. From bead cross-section after welding, penetration depth (d), bead width (W) and (d/W) ratio were obtained as shown in Fig. 1, and the relationship of these values with oxygen content of weld metal or fluid flow phenomenon of molten pool observed by CCD camera was evaluated.

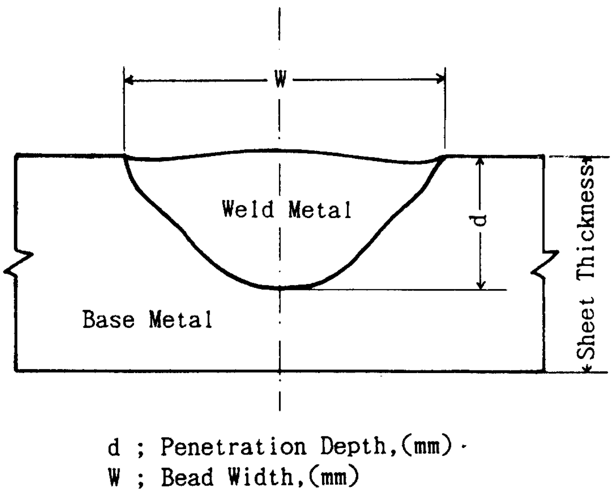

Fig.1 Definition of penetration depth (d) and bead width (W)

EXPERIMENTAL RESULTS

Fig. 2 summearizes the ratio between duration of oxidation in air and (d),(W) and (d/W) ratio for each heat input, and Fig. 3 summearizes the ralation between (d),(W) and (d/W) ratio and heat input for each duration of oxidation. As shown in Fig. 2, the influence of oxidation duration on (d) or (W) varies according to heat input, and the former increases with the increase of oxidation duration, while the latter tends to decrease. The tendency shown by (d/W) ratio is not substantially influenced by heat input and increased with almost the same (d/W) ratio with the increase of oxidation duration. Specifically, it is demonstrated that oxidation treatment of weld zone is apparently effective for the improvement of penetration property. On the other hand, when the relation of heat input with (d) and (W) is assassed for each oxidation duration, the values of (d) and (W) tend to increase with the increase of heat input as shown in Fig. 3, (bead width exhibits the trend to decrease and is reversed on high input side when oxidation duration is long). Accordingly, (d/W) ratio also tends to increase with the increase of heat input, but (d/W) ratio when no oxidation treatment is performed decreases even if heat input increases, showing that penetration is lower than the oxidized material. Thus, there is distinct difference in penetration behavior between the material with the oxidefilm and without oxide film .

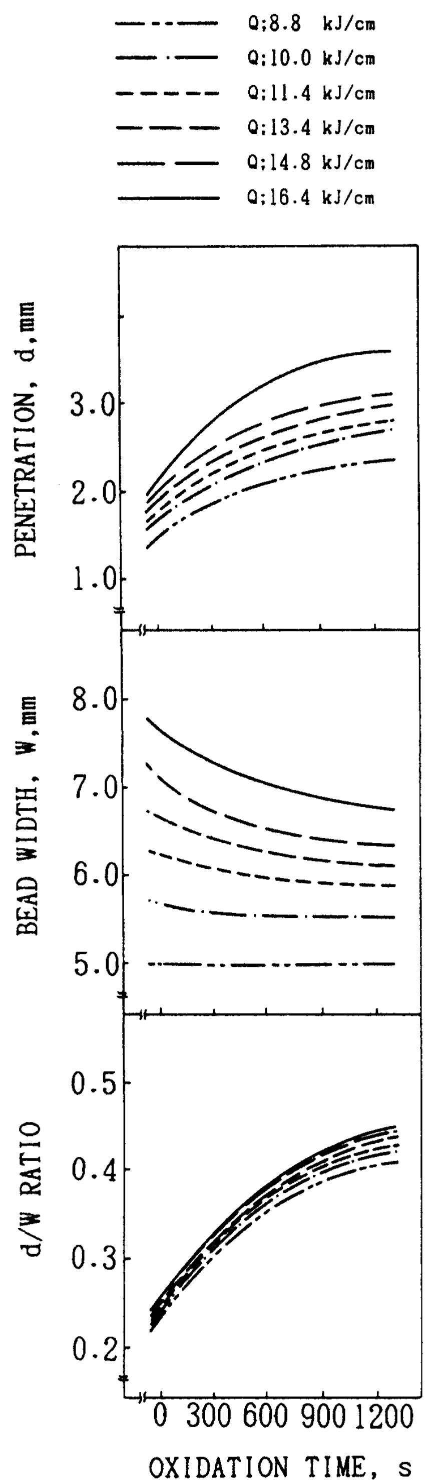

Fig.2 Effect of oxidation duration on the penetration depth, bead width and (d/W) ratio for various heat input.

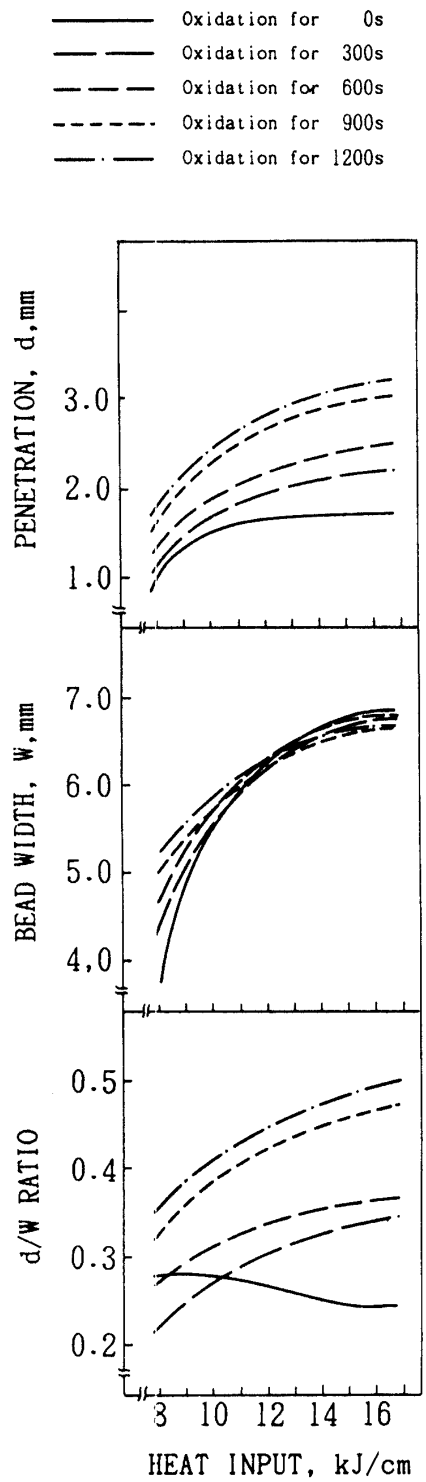

Fig.3 Effect of heat input on the penetration depth, bead width and (d/W) ratio for various oxidation duration.

DISCUSSION

As described above, there is distinct difference in penetration behavior between the material with oxide film and without oxide film. The reasons for this may be as follows : Fig. 4 shows configuration of penetration of the material with oxide film by TIG welding (oxidation duration:600 sec) and of weld zone of without oxide film for each heat input.

As it is evident from Fig. 4, bead surface of the material without oxide film is flat and penetration exhibits an arcuate and relatively shallow cross-sectional shape. On the other hand, in the material with oxide film, bead surface is elevated convexly, and penetration configuration is such that it is relatively shallow near surface while it is abruptly constricted from a certain depth and penetrated in form of a funnel,showing distinct difference in penetration configuration. In this rspect, fluid flow of the weld metal in the molten pool of the material with oxide film and without oxide film were observed by a CCD camera, through movement of Al_2O_3 particles on the molten pool. Fig. 5 shows an example, in which flow of the material with oxide film in the molten pool is directed toward the center while eddying from edge of the molten pool, whereas the flow of the material without oxide film is directed from edge to edge. Thus,

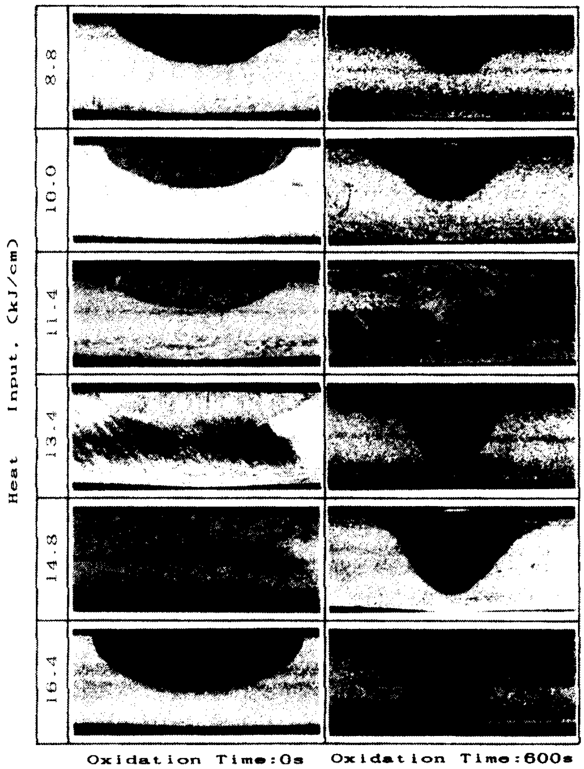

Fig.4 Examples of weld cross-section welded with various heat input on the stainless steel sheets oxidized for 0 sec(as-received) and 600 sec.

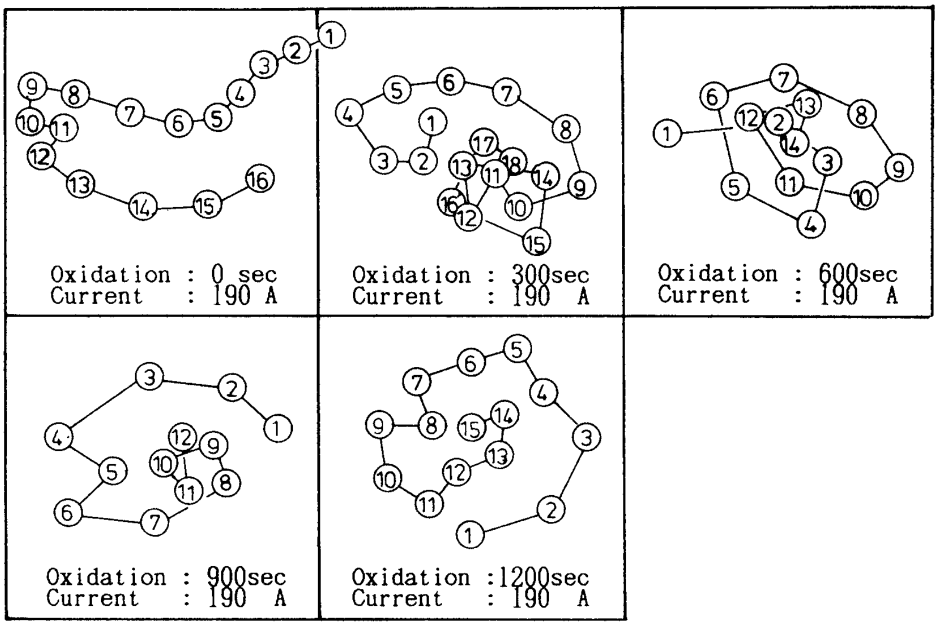

Fig.5 Examples of the locus of Al_2O_3 particle moved on the molten pool. The numbers show the location of the Al_2O_3 particle every 1/60 sec.

there was sharp difference between the two materials. Flow velocity (V) was obtained from the results of Fig. 5,and it was plotted in relation to oxidation duration as shown in Fig. 6. Fig. 6 also represents temperature difference (T_C-T_E) between edge and center of the molten pool calculated from flow velocity using the Bless's equation[4], and also oxygen content obtained from the results of analysis of the weld metal. As it is evident from Fig. 6, oxygen content in the weld metal apparently increases with the oxidation duration, while flow velocity and temperature difference also increase approximatery in proportion to oxygen content. That is, when oxygen is doped from oxide film to weld metal,flow velocity in the molten pool increases and raises heat transport efficency of arc heat and further widens temperature difference in the molten pool. Thus, heat on the surface of the molten pool is concentrated to the center of the molten pool. On the other hand, oxygen content of weld metal shown in Fig. 6 represents total oxygen content in the weld metal. For bead cross-section, oxygen distribution is obtained by CMA (color mapping analysis) of oxygen by EPMA. As a result, oxygen is present more densely near surface of the center of the molten pool when oxidation duration is short, while it is diffused and shifted toward inner part of the molten pool as oxidation duration is longer(Fig. 7). These results reveal that the flow of weld metal in the oxidized molten pool is directed from edge of the molten pool toward the center and from the center molten pool toward the bottom of the molten pool.

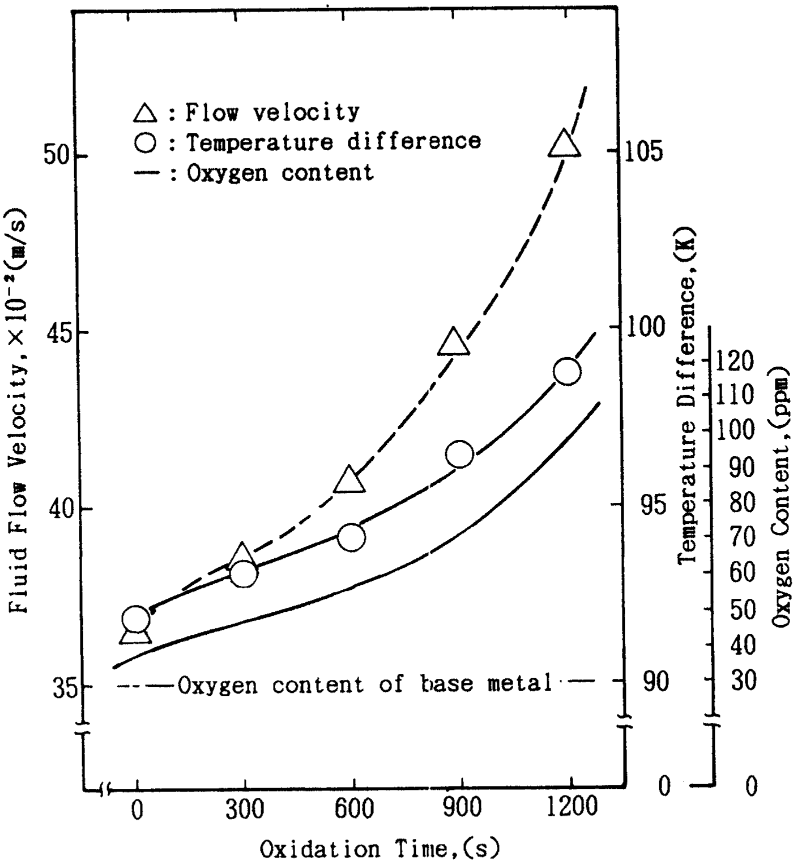

Fig.6 Relationship between fluid flow verocity on the molten pool,temperature difference and oxygen content in weld metal.

According to Heiple et al.[2][3], the flow of fluid in the molten pool is generally governed by surface tension coefficient of the molten pool. In general, metal and alloy containing lower surface active elements has negative surface tension coefficient. Because surface tension decreases with the temperature, it reaches the maximum on the edge of the molten pool where the center is higher in temperature. The flow of weld metal in the molten pool tends to advance toward the edge, and this flow is known as the so-called Marangoni effect. On the other hand, because the surface element such

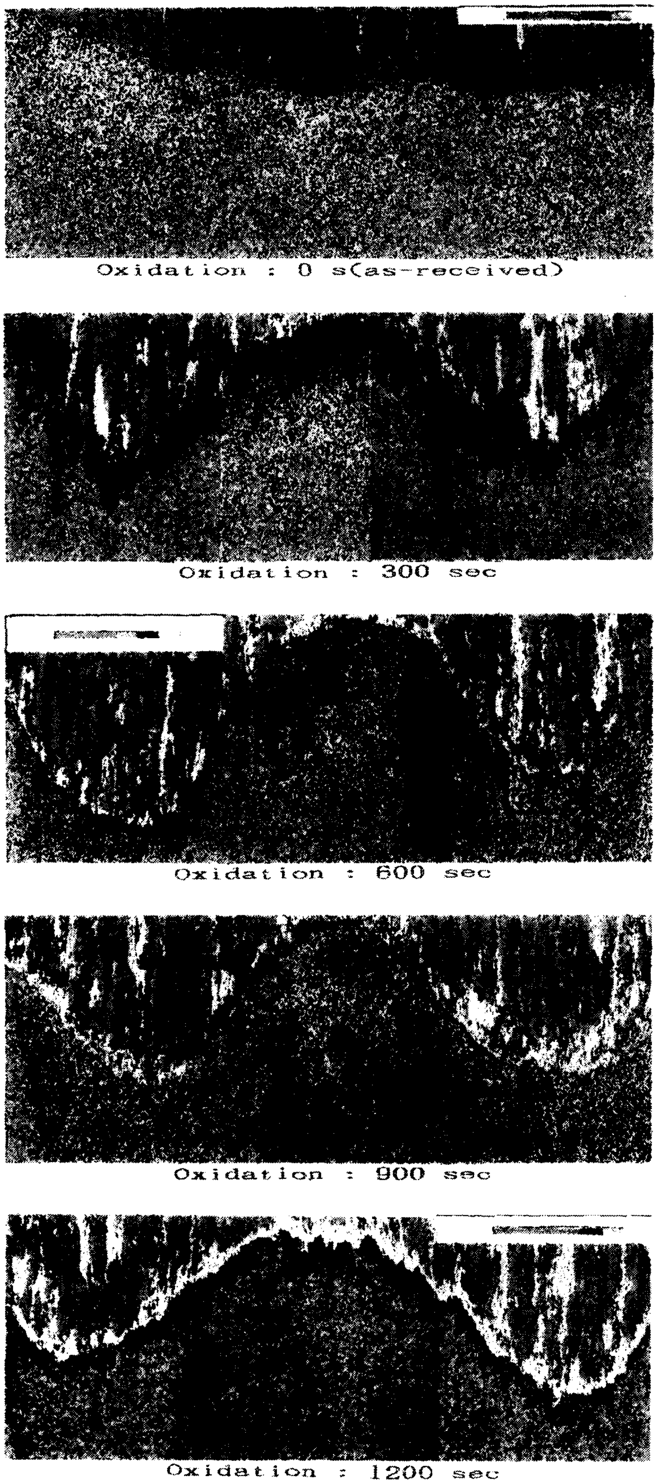

Fig.7 Examples of CMA (color mapping analysis) data of oxygen content distribution on the weld metal.

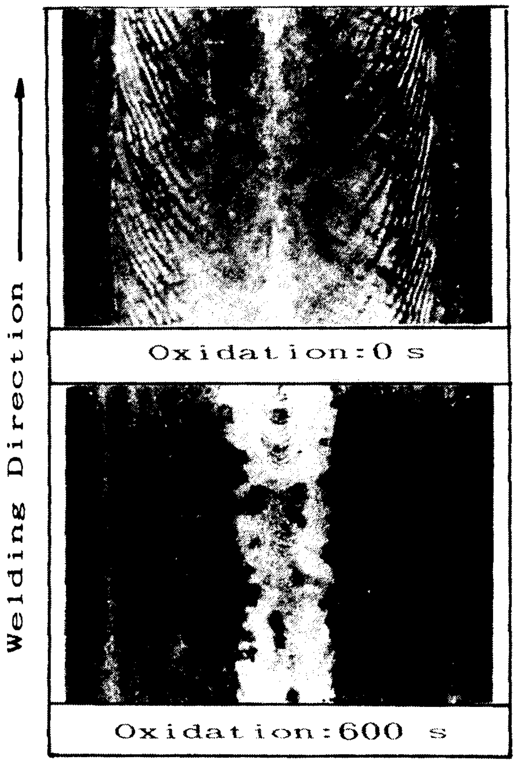

Fig.8 Examples of appearance of bead surface welded with 190 A (heat input;11.9 kJ/cm).

as oxygen changes the surface tension temperature coefficient to "positive", the surface tension reaches the maximum near the center of the molten pool, and the weld metal in the molten pool flows from the center toward the bottom of the molten pool. The pattern of this fluid flow show a tendency to effectively carry heat to the bottom of the molten pool and to form narrow but deep penetration.
On the bead surface of SUS 304, to which oxide film has been given, the oxide film is decompose by arc heat at the center of the bead as shown in Fig. 8 and the weld metal is exposed, while, in the region close to the toe of bead

edge, the weld metal is covered with oxide film. At the center of the bead where the weld metal is exposed, oxygen is present densely on bead surface as shown in Fig. 7, and this region may be considered as an area which has "positive" surface tension coefficient. On the other hand, there is little supply of oxygen in the region covered with oxide film, and this can be considered as an area which has "negative" surface tension temperature coefficient. Based on the above results, the mechanism of penetration improvement by providing the oxide film in the present study can be explained well by the model shown in Fig. 9. Specifically, in the region immediately below arc in the molten pool, the oxide film is decomposed, and oxygen is guided toward the center rgion of the molten pool. This causes "positive" surface tension temperature gradient and pulls the weld metal toward the center, thereby making the convex bead surface. This surface tension generates Marangoni convection, which is directed toward the bottom of the molten pool, and this causes deep penetration. On the other hand, outside this region, the oxide film is below its decomposition temperature, and there is little supply of oxygen. Thus, the surface tension temperature coefficient is turned to "negative", and fluid flow of the molten pool is directed toward outside, thus making the penetration shallower. As a result, penetration configurationis a combination of two types of flow, and this may have resulted in penetration in funnel shape.

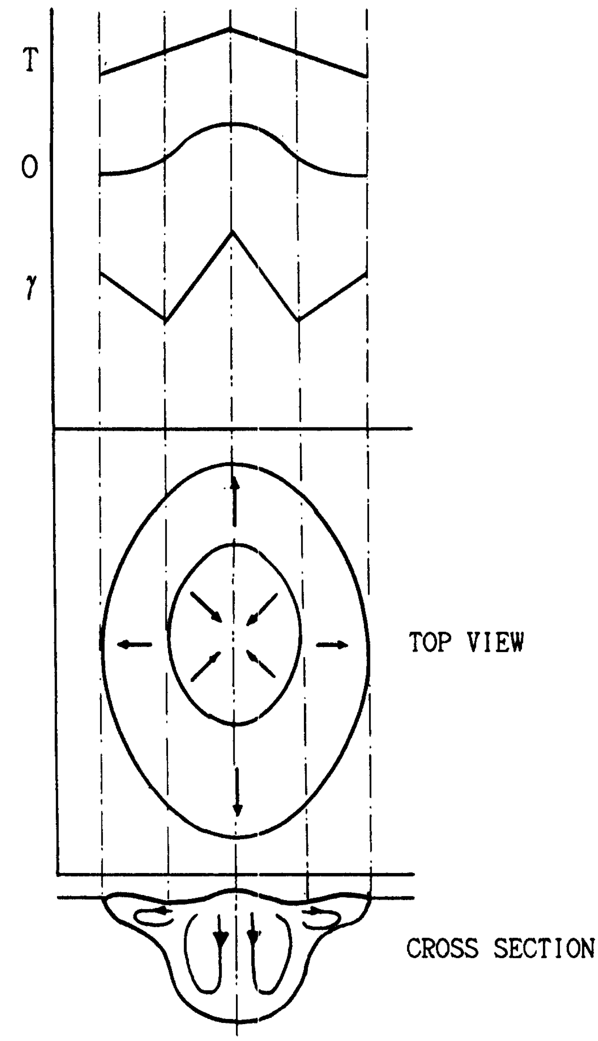

Fig.9 Schematic illustration of flow pattern in molten pool produced by decomposition of oxide film. Inside of this region under the arc allowed oxygen to enter the weld pool and produce the deep penetrating finger.

CONCLUSION

For the improvement of penetration in TIG welding of SUS 304 stainless steel sheet, the possibility to dope oxygen in the weld metal from the oxide film was evaluated. The results of the study can be summarized as follows:

(1) By giving the oxide film,(d/W) ratio, which is an index of penetration, apparently

increases, and penetration property is improved.

(2) By giving the oxide film, (d/W) ratio is increased, and the oxygen generated by decomposition of the film turns the surface tension temperature coefficient to "positive" at the center region of the molten pool,and it appears that Marangoni convection occurs, which causes deep penetration toward the bottom of the molten pool.

(3) When the oxide film is given,cross-sectional shape of the bead penetration shows the funnel like shape. This may be attributable to the fact that oxygen concentration is low on edge of the molten pool and surface tension temperature coefficient is "negative" and that Marangoni convection occurs with flow in reverse direction to that of the center of the molten pool, and these may have combined together to cause the above phenomenon.

Refarences

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