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Corrosion Characteristics of Welding Zones by Laser and TIG Welding of 304 Stainless Steel

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Two types of welding methods were performed on austenitic 304 stainless steel: laser welding and TIG welding. The differences of the corrosion characteristics of the welded zones from the two welding methods were investigated with electrochemical methods, such as measurement of the corrosion potential, polarization curves, cyclic voltammogram, etc. The vickers hardness of all laser-welded zones (WM:Weld Metal, HAZ:Heat Affected Zone, BM:Base Metal) was relatively higher while their corrosion current densities exhibited a comparatively lower value than those which were TIG welded. In particular, the corrosion current density of the TIG-welded HAZ had the highest value among all other welding zones, which suggests that chromium depletion due to the formation of chromium carbide occurs in the HAZ, which is in the sensitization temperature range, thus it can easily be corroded with an active anode. Intergrenular corrosion was also observed at the TIG-welded HAZ and WM zones. Consequently, we can see that corrosion resistance of all austenitic 304 stainless steel welding zones can be improved via the use of laser welding.

Keywords *: laser welding, TIG welding, corrosion potential, weld metal, heat affected zone, polarization curves, chromium depletion*

1. Introduction

In recent years, the use of austenitic stainless steel, which has a relatively high corrosion resistance, has been increasing due to the development of industries such as atomic energy, airplane, petro chemical, etc. When stainless steels were welded for numerous kinds of structures, intergranular corrosion would often be observed at the area surrounding the welding zones due to chromium depletion; there are numerous papers associated with general corrosion as well as intergranular corrosion.[1)-6)] It is well known that intergranular corrosion generally occurs at the grain boundary when the heating affected zone's temperature is sustained in the range from 400 ℃ to 800 ℃ for any period time, as this is the sensitizing temperature where chromium depletion acts as the anode via formation of chromium carbide. Therefore, there are some methods, such as decreasing carbon, addition of Ti, addition of Nb, solution heat treatment, etc., to control the intergranular corrosion. Recently, titanium or stainless steel with higher corrosion resistance is being widely used as the materials of heat exchangers. Futhermore laser welding is generally used to produce heat exchangers with these types of steel; although the cost of laser welding is more expensive than TIG welding. Consequently, it has been suggested that, from a long-term point of view, laser welding is more economic than TIG welding. However, there are few reported experimental results on the effects of corrosion control at the welding zones when laser welding is performed for the purpose of constructing heat exchangers with 304 stainless steel, while there is a experimental result of the effect of welding method to electrochemical behavior of automobile exhaust system with austenitic stainless steel.[7)] In this study, TIG and laser welding are performed on stainless steel and the differences of the corrosion characteristics of the welding zones were investigated with electrochemical methods. The experimental results are therefore expected to provide useful reference data for appreciation of the mechanical and corrosion characteristics of the welding zones.

2. Experimental procedure

The test metal used for the welding experiment was 304 stainless steel, which had a thickness of 1.5 mm, a width

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Table 1. Chemical compositions of 304 stainless steel.

	Cr	Ni	C	Mn	Si	S	P
min	18	8.0	0.08	2.0	1.0	0.03	0.045
max	20	10.5					

Table 2. Welding conditions for laser and TIG welding

	Welding condition
L (Laser welding)	P=2kw, V=50mm/s, Ar(15 ℓ /min)
T (TIG welding)	DC 220V, 140A, 11~13V, D.C straight polarity 2.4Φ, Tungsten bar(2.0%Th)
Filler wire(308)	C:0.05, Mn:1.85, Si:0.35, Cr:19.85, Ni:10.14

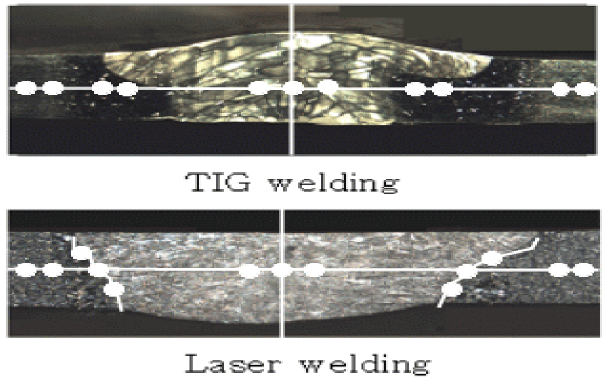

Fig. 1. Cross section view of test specimens with TIG and laser welding.

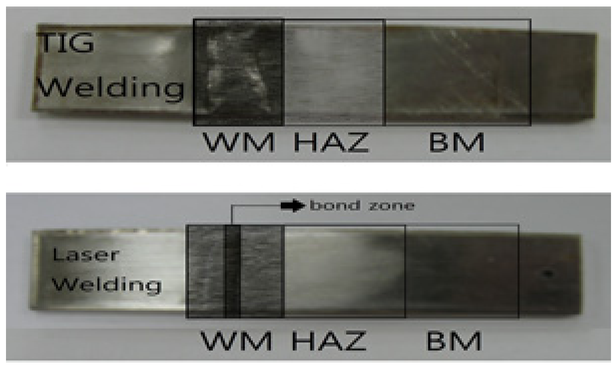

Fig. 2. Schematic diagram of WM, HAZ, and BM obtained by test specimens.

of 10 cm, and a length of 15 cm. TIG welding is a type of butt welding, while laser welding is carried out in an argon atmosphere. The chemical compositions of the test specimens are shown in Table 1 and their welding conditions are shown in Table 2.

The hardness was measured at the weld, bond, and base metal with a vickers hardness tester. And their measuring positions for hardness exhibited with white circle points as shown in Fig. 1. The hardness value of each zone was calculated as the average value of each individual value.

The surface area for the corrosion measurement such as WM, HAZ and BM is prepared with etching as shown in Fig. 2. In all cases, surface area of BM is 1 cm^2 and both HAZ and WM are 0.5 cm^2. However, in the case of laser welding, it is actually difficult to find the WM and HAZ zone clearly, therefore the range of hardness variation is qualitatively referred for determining each zone, and WM is included with both side area of right and left from central bond zone. The surface of the test specimens for the corrosion measurement were polished with sand paper (from No200 to No2000), degreased with acetone, and insulated with an epoxy coating except for area of 1 cm^2 or 0.5 cm^2 that was uncoated for the corrosion test. All measurements were performed with two specimens: one was welded with TIG welding and the other was laser welded. Corrosion potential and polarization curves were measured via the CMS 105 system (Gamry CO.UK) in a natural seawater solution (scanning speed : 1 mV/s, counter electrode : Pt wire, reference electrode : SCE); the speed was 30 mV/s when drawing the cyclic voltamogram (measuring range is from -0.5 V to 1.5 V). The surface morphology of the corroded surface was observed with an SEM microscope (Model : SV35, Sometech. Com. Ltd).

3. Results and discussion

Hardness values of each welding zone for both welding techniques are summarized in Table 3, and Fig. 3 shows the variation of hardness between TIG and laser welding. As shown in Fig. 3, hardness of the weld metal was the highest value among all other zones, regardless of the welding method. In particular, all laser-welded welding zones showed a relatively higher hardness than TIG-welded zones. It is generally accepted that the hardness of the heat affected zone increases more than other welding zones due to the quenching effect caused by quick cooling. However, in this study, the hardness of the weld metal zone increased relatively more than the heat affected zone. This is probably because various metal components are transferred from the base to the weld metal zone or from the weld to the base metal zone,[8] or the weld metal zone also contains varied dendrite microstructures, thus, the crystal grain becomes a bigger size, which results in increasing hardness.[9] In this study, it is suggested that when stainless steel is laser welded, the heat energy from the

Table 3. Relationship of variation of vickers hardness of welding zones between laser and TIG welding (Hv)

	WM	HAZ	BM	Remark
L	263	251	224	L: Laser welding
T	250	181	191	T : TIG welding

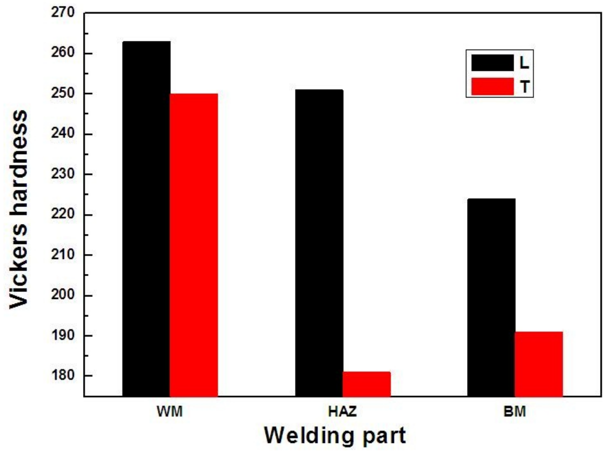

Fig. 3. Comparison of vickers hardness of welding zones between laser and TIG welding.

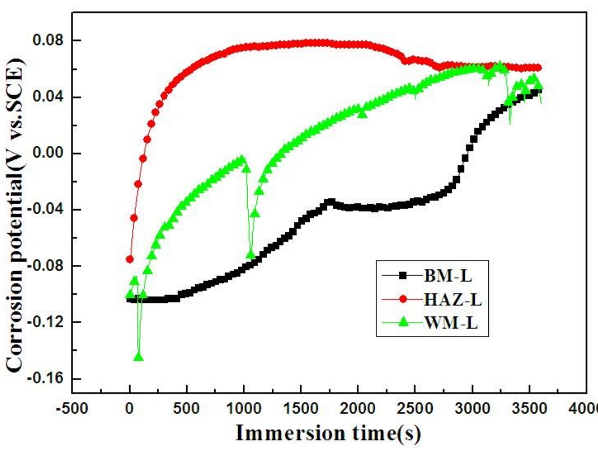

Fig. 4. Variation of the corrosion potential of welding zones in the case of laser welding.

high temperature is instantaneously supplied at the welding zone, thus the hardness of all welding zones is higher than those of TIG welding. In the case of TIG welding, filler metal consists mostly of chromium, and some of the chromium from the base metal is transferred from the base to the weld metal zone, which resulted in an increased hardness of the weld metal zone, as compared to the other welding zones.

Fig. 4 shows the variation of corrosion potentials for each laser-welded welding zone. The corrosion potential of the heat affected zone is shifted to the more noble direction from soon after immersion and the corrosion potential of the base metal exhibited a relatively more negative value than the other welding zones. Fig. 5 shows the variation of the corrosion potentials for each TIG-welded welding zone. As shown in Fig. 5, the corrosion potential of the heat affected zone showed the most negative potential and the potentials of the base and weld metal showed comparatively nobler values than the heat affected zone. From Fig. 4 and Fig. 5, we can see that the corrosion potential of the laser-welded heat affected zone is the most noble, on the other hand, its potential in the case of TIG welding is the most negative value among all other welding zones. The weld metal zone generally has a more noble corrosion potential than other zones due to the metal components added to the filler metal; its corrosion resistance is also better than other welding zones. However, in a special case, it is reported that the corrosion potential of the base metal zone is more positive than the weld metal zone.[10)]

Fig. 6 shows the variation of cathodic and anodic polarization curves for each TIG-welded welding zone. Corrosion resistance of the heat affected zone on the polarization curves is qualitatively worse than other welding zones. However, in the case of laser welding, its corrosion resistance is better than the other welding zones.

The corrosion current density of each welding zone for TIG and laser welding were obtained by the Tafel fitting method from cathodic and anodic polarization curves; their values are summarized in Table 4 and a graphical comparison of the values between TIG and laser welding is shown in Fig. 7. The corrosion current density of the weld metal zone showed the lowest value for both TIG and laser welding. However the current density of the TIG-welded heat affected zone was observed to have the highest value,

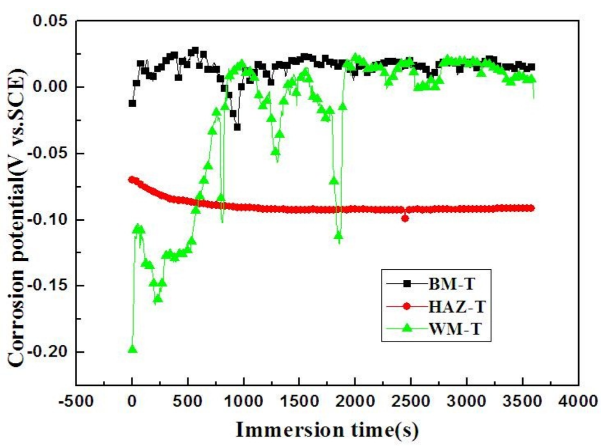

Fig. 5. Corrosion potentials of TIG-welded welding zones.

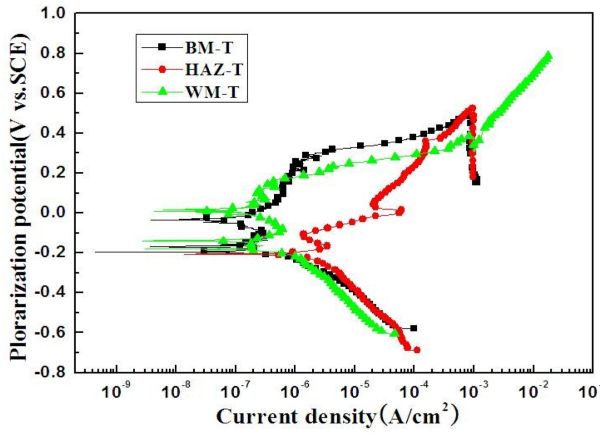

Fig. 6. Anodic and cathodic polarization curves in the case of TIG welding.

Table 4. Comparison of corrosion current densities (A/cm^2) between laser and TIG welding

	WM	HAZ	BM	Remark
L	1.9 x 10^{-8}	3.8 x 10^{-8}	8.1 x 10^{-8}	L : Laser welding
T	6.1 x 10^{-8}	5.9 x 10^{-7}	1.4 x 10^{-7}	T : TIG welding

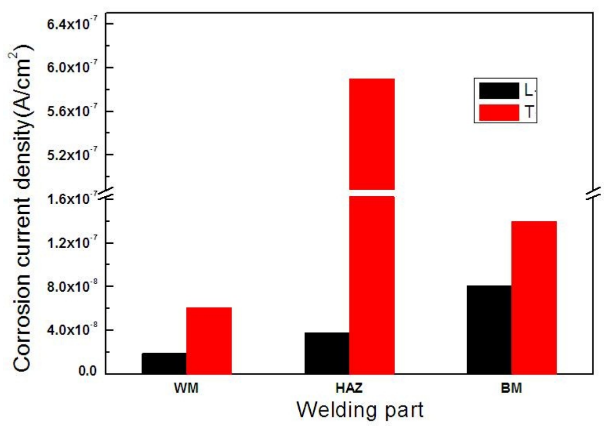

Fig. 7. Corrosion current densities of the welding zones between TIG and laser welding.

while the base metal zone had the highest value for laser welding. Moreover the corrosion current densities exhibited higher values for TIG welding than for laser welding. As a result, this suggests that the corrosion resistance of the laser-welded heat affected zone was better than that of TIG welding due to the formation of chromium oxide with an increased hardness caused by promptly supplied heat energy from the high temperature, on the contrary, the TIG-welded heat affected zone was the worst corrosion resistance because the chromium depletion zone formed at the heat affected zone due to the sensitizing temperature is preferentially corroded as the anode compared to other welding zones, and weld metal zone shows a relatively good corrosion resistance because the filler wire consists mostly of chromium and nickel as shown in Table 2, and some of the chromium and nickel are transferred from the heat affected zone to the weld metal zone, thus their oxide films are predominantly formed at the weld metal zone as follows.[11)]

$$2Cr^{2+} + 3H_2O \rightarrow Cr_2O_3 + 6H^+ + 2e$$

$$E = -0.136 - 0.1773pH - 0.0591pH$$

$$Ni + H_2O \rightarrow NiO + 2H^+ + 2e$$

$$E = 0.116 -0.0591pH$$

Fig. 8 shows the variation among cyclic voltamograms for each TIG-welded welding zone. Polarization curves of the heat affected zone are inclined to the right side

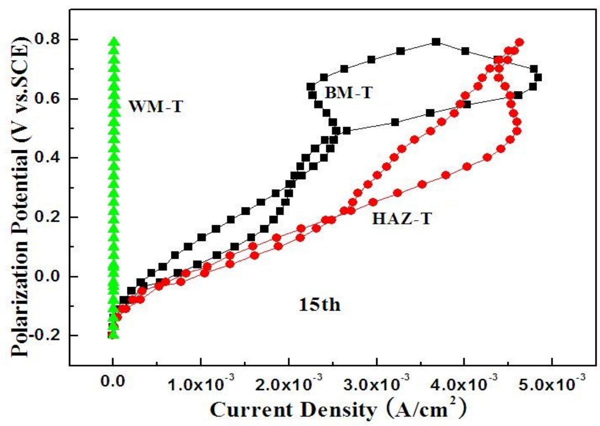

Fig. 8. Cyclic voltammograms of the 15th curve for various welding zones in the case of TIG welding.

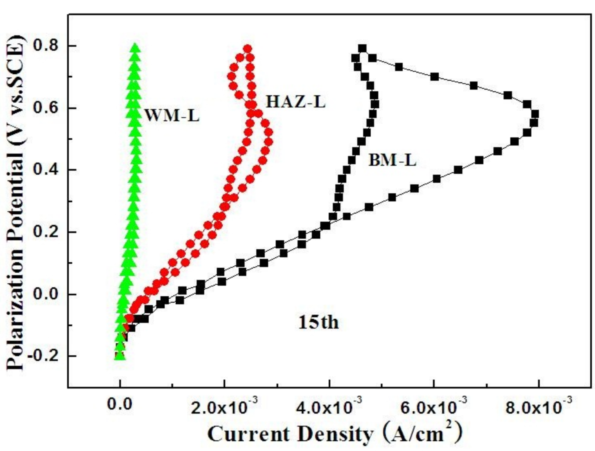

Fig. 9. Cyclic voltammograms of the 15th curve for various welding zones in the case of laser welding.

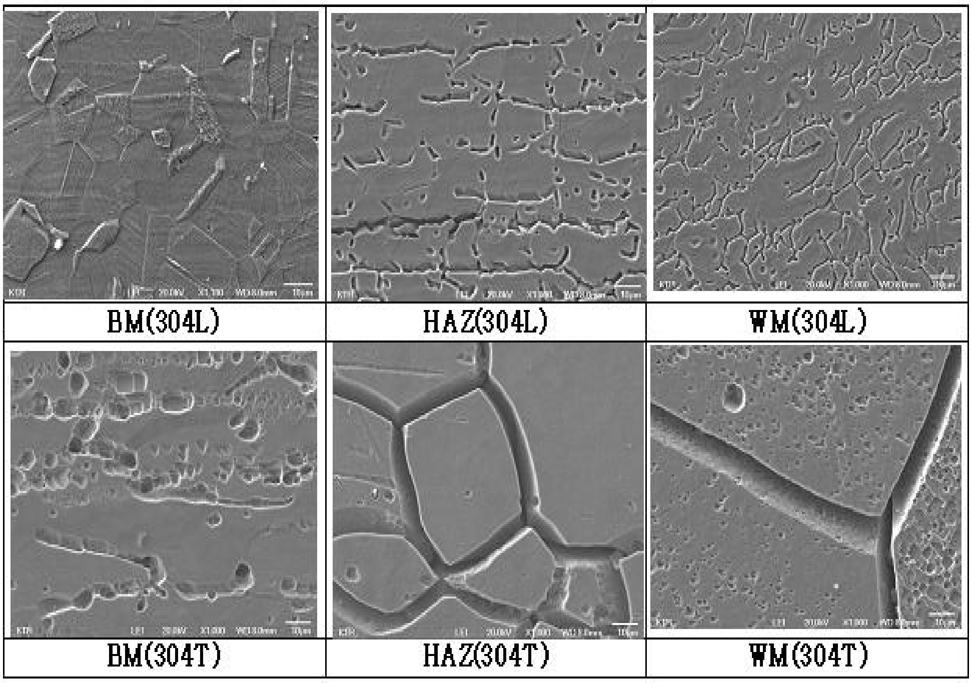

Fig. 10. SEM photographs of the corroded surface after the 15th cyclic voltammogram.

and the curve for the weld metal zone is located at the left side; however, as shown in Fig. 9, in the case of laser welding, the curve of the base metal zone is shifted the most to the right. It is generally believed that polarization resistance decreases as cyclic voltammogram curves shift from the left to the right side, and decreasing polarization resistance means the decreasing of corrosion resistance. Therefore we can see that there is a good relationship between the corrosion current density of Fig. 7 and the variation of the cyclic voltammograms of Fig. 8 and Fig. 9. For example, the increasing corrosion current density from Fig. 7 is in agreement with the tendency of the curves of the cyclic voltammograms of Fig. 8 and Fig. 9 to be shifted to the right side.

Fig. 10 shows the SEM microphotographs of corroded surfaces after the 15th cyclic voltammogram. There was little difference in the surface phenomena between each laser-welded welding zone and there was no observed intergranular corrosion at each welding zone. However, in the case of TIG welding, pitting was observed at the base metal zone and intergranular corrosion was observed at both heat affected and weld metal zones because the chromium depletion area of the grain boundary is preferentially corroded as the anode.

4. Conclusions

When TIG and laser welding were performed on 304 stainless steel, corrosion characteristics for each welding zone (base, heat affected, and weld metal zone) were investigated with electrochemical methods. The hardness of all laser-welded welding zones exhibited higher values compared to TIG welding; in particular, the TIG-welded heat affected zone was observed to have the lowest value among all other welding zones. All laser-welded welding zones have a relatively good corrosion resistance compared to those of TIG welding. Furthermore, the corrosion current density of the weld metal zone showed the smallest value among other welding zones in the case of TIG welding. Intergranular and pitting corrosion were observed at the TIG-welded welding zones, while such problems were not observed at the laser-welded welding zones. Consequently, we can see that the corrosion resistance of a welding zone is controlled by changing the welding method from TIG to laser welding.

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