Effect of Welding Shielding Gas Composition on the Properties of Laser-Arc Hybrid Welding Joint of High Nitrogen Stainless

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Abstract. In this paper, the microscopic properties and corrosion behavior of laser-arc hybrid welding joint of high nitrogen steel were studied. The electrochemical characterization of the surface layer of the welded joint under different welding shielding gas composition was obtained from the potentiodynamic polarization curve. The micro-corrosion morphology of different areas in the welded joint was analyzed by SEM, and the hardness distribution of the welded joint was measured by MH series digital hardness tester. The experimental results show that the addition of 5% CO₂ in shielding gas can improve the corrosion resistance properly, while the addition of 5% N₂ can effectively improve its passivation ability and surface hardness. The weld joint with N₂ in the shielding gas own a better transition behavior of the overall hardness distribution.

1. Introduction
High nitrogen stainless is a type of austenitic steel, its comprehensive properties are greatly improved compared with traditional low carbon stainless. The nitrogen element replaces the expensive nickel element and optimizes the properties of stainless steel [1-3]. The addition of nitrogen equivalent also increase the pitting resistance of stainless steel. However, with the increasing popularity of high nitrogen steel welding, researchers realize that compared with the high nitrogen steel base metal, its welded joints often exhibit a different corrosion mechanism [4].

With the differences of welding parameters, the weld microstructure of austenitic stainless steel formed by various solidification precipitate stable second ferrite phase [5-6] which extend along the direction of heat dissipation. Compared with the original single-phase austenite structure, the precipitation of this second dendritic structure in the weld produce a new-formed interphase potential difference. The different precipitation mode and geometric distribution of the second phase will also affect the corrosion behavior of the weld joint. It can be seen that the performance of the welded joint greatly depend on the changes of welding parameters. Rhatt et al [7] had studied the effect of shielding gas composition on the properties of welded joints of austenitic-ferritic duplex stainless. The experimental results showed that when 5%-10%N₂+Ar is used as the shielding gas for tungsten argon arc welding, the corrosion resistance of welded joints can be obviously increased.

In this paper, the laser-arc hybrid welding method is adopted, the micro-corrosion behavior and mechanical properties of high nitrogen stainless welded joints are studied. At the same time, the effects of different welding shielding gas composition on corrosion resistance and surface hardness distribution of welded joints are analyzed.
2. Experimental Method

The hybrid welding system was composed of TRUMPF HL4006D solid-state laser and Panasonic MIG/MAG welding machine. The double-heat source welding process is guided by arc in front and the laser forward. The schematic diagram of whole hybrid welding process is shown in Figure 1. The base metal materials used in butt welding is 6mm thick high nitrogen austenitic stainless. The composition of 1.2mm stainless welding wire and base metal is shown in Table 1 below. The specific welding parameters and the proportion of welding shielding gas are given in Table 2.

![Schematic diagram of laser-arc hybrid welding](image)

**Figure 1.** Schematic diagram of laser-arc hybrid welding

**Table 1.** Chemical composition of HNSS and welding wire /wt%

| Number   | C   | Si | Mn  | Cr | Ni   | N  | Mo  | S  | P  |
|----------|-----|----|-----|----|------|----|-----|----|----|
| Base metal | 0.148 | 0.49 | 16.0 | 22.07 | 0.47 | 0.56 | -   | 0.002 | 0.029 |
| Wire 2   | 0.018 | 0.48 | 1.5  | 22.7 | 8.1  | 0.16 | 3.0 | 0.003 | 0.021 |

**Table 2** Welding parameters

| Laser power P/kW | current I/A | Arc voltage U/V | speed v/m·min⁻¹ | Shielding gas % |
|------------------|-------------|-----------------|------------------|-----------------|
| 2.2              | 220         | 28              | 0.7              | 90%Ar+5%CO₂     |
| 2.2              | 220         | 28              | 0.7              | 90%Ar+5%N₂      |
| 2.2              | 220         | 28              | 0.7              | 100%Ar          |

In order to accurately measure the performance of the weld surface, the irregular residual height of the weld joint was removed. The exposed weld surface area was polished until mirrored, the electrochemical corrosion experiment and hardness test were carried out in this smooth area. The corrosion experiment used ZENNIUM electrochemical workstation, and the corrosion exposed area of weld joint was a circular region with an area of 1cm². The scanning speed was 5 mV/s, and the relative open circuit potential was ±2.5 V in the potential range. The corrosion solution is 3.5% NaCl solution, which is ventilated with Ar for at least 40 minutes before the corrosion experiment. When the open circuit potential remains stable, the corrosion test begins and the polarization curve of the weld surface is collected.

The micro-corrosion morphology is observed by scanning electron microscope (SEM). The center part of the weld was taken as the starting point to collect the micro-hardness by Vickers hardness MH series digital hardness tester.

3. Results and Discussion

3.1. Electrochemical Characterization Analysis

Figure 2 was the potentiodynamic polarization curve of each high nitrogen stainless weld sample. Electrochemical experimental results and the fitted corrosion current density (Ic) are listed in Table 3. Each sample shows a stable passivation zone, which represent that the welded joint of high nitrogen steel own excellent passivation ability. The Ic of N01 and N02 samples are almost the same which lower than that of N03 samples. It can be conclude that the corrosion resistance of N01 and N02 was relatively higher. In contrast, the passive current density (Ip) of N02 decreases obviously in the later
stage of passivation zone, which showed that N02 exhibited a better passivation characterization. This is because the N element can promote the passivation ability and pitting resistance of stainless [8-9]. The N03 weld sample with 5% N\textsubscript{2} to the welding shielding gas restrain the overflow of too much N element from the weld puddle, which finally retain more nitrogen content in the weld seam [10]. On the other hand, the addition of CO\textsubscript{2} composition in N01 welding shielding gas replenished the active gas for the welding process, which reduce the oxidation degree of the weld joint surface. This effect of preventing oxidation increase the corrosio
tion resistance of the weld surface and sub-surface indirectly.

![Figure 2. Potentiodynamic polarization curve](image)

**Table 3. Results of Potentiodynamic polarization curve**

| Unite | Weld  |   |   |
|-------|-------|---|---|
|       | N01   | N02 | N03 |
| I\textsubscript{c} \(\mu A.cm\textsuperscript{-2}\) | 7.4   | 8.8 | 17.8 |
| I\textsubscript{p} \(\mu A.cm\textsuperscript{-2}\) | 144.4 | 69.9| 144.4 |
| E\textsubscript{c} \(V/SCE\) | -0.953| -0.897| -0.668 |

3.2. **Micro-Corrosion Behavior of Weld Surface**

After electrochemical corrosion experiment, the corrosion behavior was observed by SEM. After comparative analysis, the tendency and corrosion characteristics of each welded joint exhibited a similar mechanism. Therefore, the N02 sample with the best passivation performance in the later stage was selected to analyze the characteristics of each area of the welded joint.

Figure 3 was the micro-corrosion morphology of N02 weld specimen. From the observation of the central area of the weld seam in Figure 3(a), the corrosion traces of the central weld structure showed an obvious skeleton-like shape. And the distribution of corrosion channels exhibited the same characteristics as the second-phase ferrite dendrites. It can be seen that the precipitation of ferrite dendrites increase the corrosion sensitivity between the interphase, which leads to the shedding behavior of the whole dendritic structure. With the progress of anodic reaction and the continuous advance of corrosion potential, the final corrosion channel own the same distribution state as ferrite [11].
Figure 3. Micro-corrosion morphology for each area of the welded joint. (a) Weld center, (b) Peripheral weld seam, (c) Transition zone of weld fusion line

The peripheral region of molten weld puddle near the fusion line has the highest temperature gradient and is the region where the solidification begins. Therefore, the outermost part of the weld seam owns the fastest cooling rate, and the columnar crystalline precipitated in these regions showed obvious solidification direction. As shown in Figure 2 (b), for peripheral weld seam in the outside, the density of corrosion traces increased and accompanied by a certain directionality. This phenomenon further proved that ferrite dendrites induce the formation of corrosion channels. The continuous corrosion channels gradually tend to accumulate together. Figure 3 (b) represents the corrosion morphology around the fusion line. Compared with the interphase corrosion in weld seam, the serious shedding corrosion was observed on the heat-affected zone (HAZ) outside the fusion line. This is because the outer base metal with semi-molten state obtain a short heat treatment effect under the action of high temperature molten weld puddle. The grains at the outer HAZ of the fusion line were grown by heating effect, which greatly increasing the intergranular sensitization and ultimately reducing the corrosion resistance.

It can be conclude that in the welded joint, the transition region between the base metal and the weld structure is the area with weak corrosion resistance.

3.3. Micro-Hardness Analysis of Weld Joint

In Figure 4 (a)-(b), the micro-hardness of each area of the welded joint with different welding shielding gas is collected. The horizontal hardness distribution of different welded joints shows a ladder characteristics. The hardness in the center part of the weld seam is the lowest. The closer to the fusion line, the hardness increases gradually. Until it is close to the base metal, the micro-hardness reaches the maximum.

Figure 4. Hardness distribution of welded joint. (a) Weld hardness distribution, (b) Fitting hardness tendency
Figure 4 (b) is the corresponding hardness curve fitted according to the hardness tendency. From the comparison of curve width and transition characteristics during high-low hardness transitional region, the weld center of N03 is relatively lower than that of N01 and N02, and the whole transition mode of N01 and N02 is smoother. The addition of shielding gases of N\textsubscript{2} optimized the solidification process and improved the minimum hardness of the weld joint. Zhang\textsuperscript{[10]} also reached a similar conclusion, adding a small amount of N\textsubscript{2} to the shielding gas can effectively improve the hardness of stainless welded joints.

4. Conclusion
In this paper, the properties of laser-arc hybrid welding joints under different welding parameters are studied, with emphasis on the micro-corrosion characteristic and surface hardness distribution. The specific experimental conclusions are as follows:

(1) The corrosion resistance of the laser-arc hybrid welding system can be improved by adding 5\% CO\textsubscript{2} or 5\% N\textsubscript{2} to the welding shielding gas, the weld seam with 5\% N\textsubscript{2} exhibited better passivation ability.

(2) The precipitation of ferrite phase in the weld seam induced continue skeleton-shape corrosion traces along the dendrites. The corrosion behavior around the weld fusion line tend to deteriorate. The microstructure around the weld fusion line exhibited serious shedding behavior.

(3) The hardness in the center weld was lower than that of the fusion line and the base metal, the micro-hardness of the weld joint showed a ladder-like distribution. Compared with pure Ar welding shielding gas, the addition of 5 \% N\textsubscript{2} and active CO\textsubscript{2} can appropriately increase the minimum hardness of the weld center and optimize its transition zone.

5. References
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