Study on PAW + TIG hybrid welding process of pure nickel straight pipe

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Abstract: The straight nickel pipe is made of the roll forming machine, and the welding process is the key factor to ensure the quality of the nickel pipe. The plasma arc welding (PAW) and plasma arc welding (PAW)+tungsten inert gas (TIG) hybrid welding were used to prepare specifications for 112 mm×3.5 mm×6 500 mm pure nickel pipe, respectively. The microstructure and mechanical properties of the weld appearance were analysed. The results show that the PAW+TIG hybrid welding achieves ‘single pass, doubleformed’ at the thickness of pure nickel 3.5 mm straight seam welded pipe. It can be derived from the macroscopic morphology of PAW+TIG recombination welding line that PAW+TIG recombination welding realize the one side welding both sides formation of 3.5 mm thickness pure nickel longitudinal welded pipe. It effectively avoids undercut, sunken, air hole and other defects, the formation of welding line of PAW+TIG recombination welding is well. The welding line of pure nickel longitudinal welded pipe suffered the second heat of TIG arc, this caused the grain growth in weld zone and heat affected zone, the organization in heat affected zone consist of big isometric crystal, the average size is 103.75 μm, while the organization in weld zone is directional columnar crystal with the average size of 547.32 μm. The tensile strength reaches 321 MPa with the elongation being 30.46%, which reaches the strength of the base material 85.6%. At the same time, the TIG arc prolonged the residence time of molten pool and the un-escaped gas is escaping from the re-flowing molten metal, thereby the porosity in the weld was eliminated.

Key words: PAW+TIG; pure nickel straight pipe; plasma arc welding
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0 Introduction

Nowadays, the pipeline transportation is the main component of integrated transportation system, which is the basic industry of the social and economic development with railway, highway, waterway, and aviation industries[1]. The pure nickel possess excellent corrosion resistance with a higher vacuum performance and electromagnetic control performance, and has a good corrosion resistance when it In the environment of caustic soda[2,3]. Therefore, nickel and nickel alloy tube has been widely used in alkali industry, chloralkali chemical and organic chloride production, food processing, high temperature and salt halogen corrosion environment, electronic instrument parts, water treatment, alkali resistant equipment etc. So far, at home and abroad nickel and nickel alloy tube gives first place to seamless extruded tube, which manufacturing process is complex, the product quality is unstable, uneven thickness, low brightness, light tube surface and the qualification rate of the product is only 30%~40%, some high-end nickel alloy pipe completely rely on imports. The pure nickel longitudinal welded pipe, which can effectively avoid the problems caused by
the extrusion process, and has simple manufacturing process, stable product quality, from the plate to pipe the qualification rate of the product can reach more than 85%, and the production cost is low. Compared with the nickel tube extrusion welded pipe, ERW pipe has great advantages, this paper chooses a reasonable welding method to carry out the research work of pure nickel welded pipe based on these reasons and has got a certain achievements.

The plasma arc has a high energy density and a strong penetrability, which can penetrate the molten pool directly and form a small hole through the thickness of the workpiece[6,5], the keyhole effect is a special phenomenon in plasma arc welding process, which is helpful for the full penetration of the welded workpiece[6]. Plasma arc welding (PAW)+tungsten inert gas (TIG), which mainly used good penetration ability of the plasma arc welding (PAW)[6], is to ensure weld quality and as far as possible to improve the welding speed. And the free-burning arc of TIG has a good covering ability, which improve the welding seam forming[5]. Test were performed by PAW and PAW+TIG methods with contrasting the difference between two kinds of welded pipe, and determined the reasonable welding method and welding process, in order to provides experience and theoretical guidance for developing a pure nickel welded pipe of meet the working conditions.

1 Test procedure

The material used for the test is annealed pure nickel N6 nickel plate, the thickness is 3.5 mm, and the chemical composition and physical properties are shown in Table 1 and Table 2. The welding equipment is PHM-500 plasma welding machine and WS-400 argon arc welding machine, straight nickel tube forming equipment using improved ZG pipe machine, as shown in Fig.1. The forming process of pure nickel straight welded pipe can be divided into the following steps: rough forming, intermediate forming (combination roll), precision forming, extrusion welding, sizing, straightening and cutting, and welding is the key to ensure the quality of nickel pipe.

Pure nickel ERW uses improved Z pipe machine realizing natural molding, using pure nickel N6 3.5 mm thick plate from the middle to the end of the vertical tail of the successive bends into the shape of "U", became "C" shape, and ultimately the formation of "O" cylindrical shape, weld zone welding nickel plate at the two edge formed 1~3 mm gap, respectively using PAW and PAW+TIG hybrid welding of two methods and all the welding parameters in the optimal (see Table 3)[10] for welding, welding material without filled in the welding process, prepare specifications for 112 mm×3.5 mm×6500 mm pure nickel straight welded pipe. Before welding, use 600# sandpaper to polish the surface of the nickel plate groove and welding seam, and remove the oxide film on the surface, and wash with acetone removing the surface oil.

After welding, according to the GB/T2651-2008 standard for making the tensile specimens which were used the WDW-100E universal material testing machine to test two types of weld tensile strength and elongation after fracture; cut out the weld of the pure nickel seam welded pipe production from metallographic sample, using mixed acid solution (CH₃COOH:HNO₃:H₂O=4:4:2) on the corrosion of the metallographic sample, and then placed in the MeF3 microscope to observe the regional morphology; parallel in the nickel tube welding direction interception of longitudinal seam, observing the macro morphology of weld: using scanning electron microscope (SEM) tensile fracture morphology of weld were analyzed.

### Table 1 Chemical composition of N6 (mass fraction, %)

<table>
<thead>
<tr>
<th>Element</th>
<th>Mass Fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni+Co</td>
<td>99.5</td>
</tr>
<tr>
<td>Mn</td>
<td>0.05</td>
</tr>
<tr>
<td>Fe</td>
<td>0.10</td>
</tr>
<tr>
<td>Si</td>
<td>0.002</td>
</tr>
<tr>
<td>P</td>
<td>0.002</td>
</tr>
<tr>
<td>other</td>
<td>≤0.50</td>
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</tbody>
</table>

### Table 2 Physical properties of N6

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density ρ/g·cm³</td>
<td>8.89</td>
</tr>
<tr>
<td>Melting point T/℃</td>
<td>1453</td>
</tr>
<tr>
<td>Resistivity ρ/Ω·m</td>
<td>6.84</td>
</tr>
<tr>
<td>Thermal conductivity λ/W·(m·K)⁻¹</td>
<td>92</td>
</tr>
<tr>
<td>Specific heat c/J·(kg·K)⁻¹</td>
<td>0.64</td>
</tr>
</tbody>
</table>

### Table 3 Welding Parameters

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Gas flow rate Q/L·min⁻¹</th>
<th>Welding speed v/mm·min⁻¹</th>
<th>PAW shielding gas Q/L·min⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAW</td>
<td>2.5</td>
<td>255</td>
<td>15</td>
</tr>
<tr>
<td>PAW+TIG</td>
<td>2.5</td>
<td>295</td>
<td>15</td>
</tr>
</tbody>
</table>

2. Test results and analysis

2.1 Plasma arc welding of pure nickel straight welded pipe (PAW)

In this paper, the welding procedure test of pure nickel straight welded pipe with thickness of 3.5 mm was carried out by using the PAW welding parameters in table 3. Pure nickel longitudinal welded by plasma arc welding surface prone to defects such as undercut, depression, as shown in Fig.2(a), which is due to plasma arc stiffness and arc column thin. Therefore, the welding arc has a great blow force to the liquid metal in the welding pool, resulting in the molten
metal sinking; what’s more, the weld metal solidification speed is fast. welding material is not filled in the welding process, the sinking of the molten metal can not supplied in time, which easily leading to undercut, depression and other defects: at the same time the PAW welded joint of the seam welded pipe is easier to form pores. As shown in Fig.2(b) shows, it is because: that firstly, pure nickel liquid metal is stickiness and has a poor fluidity, and solid-liquid phase temperature range is small, which more easily from the air to absorb the gas and gas solubility in molten pool is bigger in the welding process, and the process of cooling and the solubility of gas in liquid metal decreases sharply because of high viscosity and poor fluidity, resulting in gas floatation speed hindered in molten metal solidification process and can not have any way in a short period of time all rose to the surface of the molten pool in the overflow: secondly, the pure nickel thermal conductivity is low, the pool size from plasma arc welding is small, the contact area of the weld surface is large, cooling speed is fast, and molten pool residence time is relatively short, the first occurrence of solidification on the weld surface, which lead to weld gas dissolved in not enough time to overflow and eventually formed gas hole.

The experment was found that the defects such as undercut and porosity are easily occur to the plasma arc welding seam. The weld porosity reduces the effective cross-sectional area, and around the pores produces stress concentration, reducing the strength and toughness of the weld, which is more unfavorable to the welding components of the dynamic load strength and the fatigue strength, in certain circumstances it may also cause cracks[9-10], therefore, the method of the single plasma arc welding is not suitable for the welding of the pure nickel pipe.

2.2 PAW+TIG hybrid welding for pure nickel straight seam pipe

When the pure nickel pipe was welded by PAW, the weld seam was easy to appear undercut and porosity. Therefore, the PAW+TIG hybrid welding was proposed to weld the pure nickel straight pipe. This composition of the apparatus is schematically shown in Fig.3 in which
the axis of the PAW and TIG torch is arranged in a straight line. Both the TIG torch and PAW torch were clamped by a special fixture, which could adjust the distance, axiality and heights of the torches. PAW torch was installed in front of TIG torch, in which the characteristic of PAW-TIG hybrid welding is that the two arcs have no interacting in this process. The distance between the centers of two torches (d) was kept at the range of 120~200 mm in the whole welding process.

The pure nickel straight pipe, with having ‘single pass, double-formed’ and beautiful formation characteristics, is realized by using PAW+TIG hybrid welding and the defects such as undercut, burn through and crater are completely eliminated, as shown in Fig 4 (a). When the material was firstly melted by the heat input of the PAW arc, owing to the stability of the keyhole status and the PAW arc the weldment was easy to appear undercut and burn through. With the nickel tube continuing to move forward, adding a stable TIG arc can cause the remelting of the weld metal. Due to the relative dispersion of TIG arc energy density, the pool area was expanded with the molten metal around weld pool refilling the depressed weld, which was conducive to eliminate defects. And full penetration welds with good geometrical consistency, uniform scale shape was obtained. At the same time, the TIG arc prolonged the residence time of molten pool and the un-escaped gas is escaping from the re-flowing molten metal, thereby the porosity in the weld was eliminated, as shown in Fig. 4 (b).

2.3 Microstructure and mechanical properties of welded joints

The microstructure of hybrid welding joint is shown in Fig.5. The microstructure observation shows that the base material, with grain boundaries being clear, is a homogeneous and small austenite grain with the average grain size of 47.32 μm. Due to the remelting effect of TIG arc, the microstructure size of PAW+TIG joint is larger than PAW joint; the heat affected zone is equiaxed grain structure with an average grain size of 103.75 μm; and the coarse columnar crystal structure is formed in the weld metal with an average grain size of 547.32 μm.

In the process of PAW+TIG hybrid welding, the weld is firstly heated by the PAW arc. With the forward motion of the nickel tube, the welding seam reaches the TIG welding zone, the weld metal heated by the PAW arc is reheated by the TIG arc. That is, the weld metal is remelted. The pure nickel N6 is a single phase austenite with no phase transformation occurring during heating and cooling process. And the heating process caused grain coarsening. However, during the cooling process of the molten pool, the grain would not be refined due to the recrystallization caused by the phase transformation. So the grain was second-crystallization owing to the TIG arc effect. Grain boundary migration rate increased and grew up by annexing the surrounding...
small grains with grain boundary migration to form large grain during the process of welding. Therefore, the grain size of the weld metal (WM) and heat affected zone (HAZ) of hybrid welding joint is obviously larger than that of PAW welding method.

The fracture location of the hybrid joint is the weld with the elongation being 30.46% and the ultimate tensile strength reaches 321 MPa, which reached 85.60% of the base metal strength (375 MPa). It can be seen that the above ultimate tensile strength of hybrid joint can fully meet the requirements of mechanical properties of nickel pipe. At the same time, hybrid welding eliminates undercut, porosity and other defects of single PAW process and significantly improve the weld performance and yield.

The fractured surfaces of the tensile specimens were analysed using SEM. Fig.6 shows the SEM fractographs of all the joints tensile tested. From Fig.6a it is observed that fractured surface of base metal contains a large population of uniform dimples and clear tear ridge. Snake pattern appears on the inner wall of the dimple. The plastic deformation of the base metal under the action of stress leads to the formation of microholes, which is accompanied by the continuous action of the stress. With the continuous action of stress the growth and aggregation of micro holes forms large voids and further connects together, which leads to the fracture of the material. So the base metal fails in a ductile manner under the action of tensile loading. As shown in Fig.6b there is a quantity of big shear dimples and tearing ridge. So the fracture mode of hybrid joint is mixed fracture, in which the ductile fracture is major.

3 Conclusions

(1) Plasma arc welding (PAW) can realize the one side welding both sides formation of 3.5 mm thickness pure nickel, meanwhile, as the low mobility of pure nickel, the high viscosity and the wees arc stream of plasma, the welding line might have defects such as undercut, sunken and air hole.

(2) It can be derived from the macroscopic morphology of PAW + TIG recombination welding line that PAW + TIG recombination welding realize the one side welding both sides formation of 3.5 mm thickness pure nickel longitudinal welded pipe, the method also effectively avoids undercut, sunken, air hole and other defects, the formation of welding line of PAW + TIG recombination welding is well.

(3) The welding line of pure nickel longitudinal welded pipe suffered the second heat of TIG arc, this caused the grain growth in weld zone and heat affected zone, the organization in heat affected zone consist of big isometric crystal, the average size is 103.75 μm, while the organization in weld zone is directional columnar crystal with the average size of 547.32 μm.

(4) The extension strength of weld zone prepared by PAW + TIG recombination welding can reach about 85.60% of the base metal, the position of tensile failure all happened in weld zone and it belongs to ductile fracture. The properties of pure nickel longitudinal welded pipe prepared by PAW + TIG recombination welding can totally meet the mechanical properties request in practical production. Meanwhile, PAW + TIG recombination welding effectively avoids defects emerged in single plasma arc welding, defects can be undercut, sunken, air hole and so on, while this method can prepare good properties weld zone with fine figure of fish scale surface morphology, the yield of longitudinal welded pipe increased remarkably. Therefore, PAW + TIG is the best method to prepare pure nickel N6 longitudinal welded pipe.

Reference


