Study on the Microstructures and Properties of 904L Super Austenitic Stainless Steel Rolled Clad Plate

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Abstract. The microstructures and properties of 904L super austenitic stainless steel rolled clad plate were studied. The microstructures and properties of base metal and welding joint of 904L rolled clad plates were studied and analyzed by means of optical microscope, intergranular corrosion and electrochemical methods. The results showed that the clad plate had a good compound effect, and the tensile, bending, shear and impact properties of the base material and welding joint meet the standard requirements. Besides, the intergranular corrosion and electrochemical analysis showed that the base metal and welding joints of 904L had good corrosion resisting properties for the high self-corrosion potential and electrochemical impedance.

1. Introduction
904L is a kind of super austenitic stainless steel, which has high strength, high hardness, good impact toughness and welding performance with low carbon, high nickel, chromium, and a small amount of copper alloy system[1-2]. It is widely used in petroleum, chemical engineering, marine engineering, salt and paper industry for the strong ability to resist high temperature creep and excellent resistance to stress corrosion, crevice corrosion and uniform corrosion.[1-5]. It is difficult to manufacture and apply for the high cost and price, due to the high content of alloying element in 904L.

With the development of progress for metal layer composite technology, super austenitic stainless steel - carbon steel clad plate have been developed. This kind of clad plate with super corrosion resistance of austenitic stainless steel and strong toughness of carbon steel can reduce the amount of 904L in the same thickness, thus it has higher efficiency and significantly lower engineering cost. So 904L and other stainless steel clad plates have been widely used in petroleum, chemical, metallurgy and other fields[6-9]. The microstructures and properties of base metal and the welding joint of the 904L rolling clad plate were analyzed in this paper, in order to evaluate the mechanical properties and corrosion resistance and provide a reference for the practical application of this kind of clad plate.

2. Experimental materials & procedures

2.1. Experimental materials
The test materials are the base metal and welding joint of 904L+Q345R made of Q345R and 904L by hot rolling. The diagrammatic drawing and the chemical composition of tested steel are shown respectively in figure 1 and table 1.

The butt welding joint were got with the groove type shown in figure 2, and welding sequence is that the base metal first, then transition layer, and finally the stainless steel layer with the welding rods.
are CHE507R, CHS042 and CHS385 respectively. The composition of welding materials are shown in table 2.

![Diagrammatic drawing of the clad plate](image)

**Figure 1. Diagrammatic drawing of the clad plate**

| Grade  | C   | Si  | Mn  | Ni   | Cr  | Mo  | Cu  | Fe  |
|--------|-----|-----|-----|------|-----|-----|-----|-----|
| Q345R  | 0.18| 0.35| 1.45| ≤0.1 | ≤0.1| ≤0.1| -   | Bal.|
| 904L   | 0.017| 0.25| 1.40| 26.1 | 19.1| 4.7 | 0.9 | Bal.|

![The groove type of butt welding of clad plate](image)

**Figure 2. The groove type of butt welding of clad plate**

| Grade  | C     | Si  | Mn  | Ni     | Cr     | Cu   | Mo  | Fe  |
|--------|-------|-----|-----|-------|--------|------|-----|-----|
| CHE507R| 0.097 | 0.53| 1.03| 0.014 | 0.032  | 0.016| 0.0041|
| CHS042 | 0.026 | 0.55| 0.96| 13.38 | 23.01  | 0.026| 2.26 |
| CHS385 | 0.028 | 0.28| 1.60| 24.15 | 21.00  | 1.48 | 4.62 |

2.2. **Experimental procedures**

The base metal and welding joint are got from quarter width of steel plate, the tensile test, shear strength testing, bend testing and impact testing are according to ASTM A264 and the samples for optical microscope (OM) were etched in 4% nitric acid alcohol solution and copper sulfate and hydrochloric acid aqueous solution (1:5:5). The intergranular corrosion testing carried out by the E method of ASTM A262. In addition, the electrochemical polarization curve of the samples were determined by the Parstat2273 electrochemical test system, and the electrochemical impedance spectroscopy of 904L were characterized also.

3. **Results and analysis**

3.1. **Microstructure and properties of base metal**

3.1.1. **Microstructure of base metal**

The microstructure of 904L+Q345R rolling clad plate were shown in figure 3. It can be seen that the microstructure of base metal are ferrite and pearlite. The interface is compact and smooth, and the ferrite features are relatively obvious, near the interface of the carbon steel side, which indicated that there is a certain carbon diffusion near the interface. The microstructure of stainless steel is austenite with a small number of twin crystals, and there is no precipitates on grain boundaries.
3.1.2. Properties of base metal

The mechanical properties and corrosion resistance of 904L+Q345R rolled clad plates were tested and evaluated, and the results were shown in table 3 and figure 4. It can be seen from table 3 that the clad plate has good bending performance and shear strength reaches 344MPa (far higher than the standard requirement of 210MPa), which indicates that the clad plate has a good compound effect. Yield strength, tensile strength, break elongation of carbon steel all meet the requirements, impact energy at 0℃ is 241J. It suggests that carbon steel has good toughness. Yield strength, tensile strength, break elongation, hardness and intergranular corrosion of stainless steel all meet the requirements, it shows that the clad layer of 904L+Q345R has good strong toughness and corrosion resistance also.

In addition, according to the results of electrochemical analysis shown in figure 4, 904L has a higher corrosion potential and electrochemical impedance with wider passivation range. This electrochemical characteristics provide the basis for its good corrosion resistance, related research has a similar conclusion[4-5]. It further evidence that 904L have a good corrosion resistance with the rolling clad process.

Table 3. Properties of the base metal of test steel

| Position  | Size mm | Rp0.2 MPa | Rm MPa | A % | KV2,0℃,J | HRB | Intergranular corrosion |
|-----------|---------|-----------|--------|-----|-----------|-----|------------------------|
| Base layer|         |           |        |     |           |     |                        |
|           | 47      | 369       | 567    | 29.5| 241       | -   | -                      |
| Standard  | ≥315    | 490~620   | ≥21    | ≥41 | -         | -   |                        |
| Clad layer| 3       | 427       | 590    | 36.0| -         | 80.68| Good                   |
| Standard  | ≥220    | ≥490      | ≥35    | -   | ≤90       | Good|

Note:  
(1) Shear strength of the test plate is 344MPa, and the standard requirement is greater than 210MPa;  
(2) Intergranular corrosion was carried out in reference to ASTM A 262-E.

3.2. Microstructure and properties of weld joint

3.2.1. Microstructure of weld joint

The microstructure of the weld joint of carbon steel layer and stainless steel layer of 904L+Q345R were observed, and the results were shown in figure 5 and 6. It can be seen from Fig.5 that the microstructure of carbon steel is acicular ferrite and first eutectoid ferrite (Fig.5a), the microstructure
of stainless steel are mixed with proeutectoid ferrite and acicular ferrite (Fig.5b), due to effect of subsequent weld heat treatment, but there was no sign of melting into the stainless steel components. The microstructure in the coarse grain area of welded joint is low carbon bainite (Fig.5c), indicating the excellent welding properties of the carbon steel. The weld zone have obtained excellent metallographic structures with fine grain size (Fig.6), suggests that welding process is reasonable, which has laid the foundation for its good mechanical properties also. In addition, the composition of the weld zone was analyzed, and the results were shown in table 4 with high content of Cr, Ni and Mo, which provided a guarantee for its good corrosion resistance.

![Figure 5](image1.png)

**Figure 5.** Microstructure of carbon steel side(a), stainless steel side(b) and coarse-grain zone of carbon steel(c) in welding joint of 904L+Q345R

![Figure 6](image2.png)

**Figure 6.** Microstructure of cap weld(a) and coarse-grained zone(b) in the welding head of stainless steel layer in 904L+Q345R

**Table 4.** Composition of the welding one (wt. %)

| C   | Si  | Mn | Ni  | Cr  | Cu  | Mo |
|-----|-----|----|-----|-----|-----|----|
| 0.032 | 0.36 | 1.62 | 23.38 | 20.45 | 1.05 | 2.63 |

3.2.2. **Properties of weld joint**

The mechanical properties (including tensile, bending and impact properties) and the intergranular corrosion resistant ability of welded joint were tested, the results were shown in table 5 and figure 7. The tensile properties and impact toughness of welded joints meet the technical requirements with large allowance and bend test is qualified, as seen from table 5. In addition, it shows good intergranular corrosion resistant ability of 904L sampling from the weld zone and heat affected zone (HAZ) after continuous soaking boiling sulfuric acid and copper sulfate solution for 16 hours with no cracks (Fig. 7). It provided the guarantee for the good corrosion resistance of the welded joint for the process of production and welding avoided the harmful precipitation interval of 904L.

**Table 5.** Properties of the weld joint of test steel

| Tensile properties | Bend test | Impact property, 0℃ |
|--------------------|-----------|---------------------|
| U.T./MPa | Cracked position | Side bend | Position | Weld zone/J | HAZ/J |
| Weld joint | 617 | Base metal | OK | 1/4T | 172 | 181 |
| | | | | 1/2T | 150 | 148 |
| Standard | 490–620 | OK | | | ≥41 |
4. Conclusion
It can be seen from the study that the composite effect of 904L+Q345R clad plate by rolled is very good, and the shear strength is higher than 344MPa. The mechanical properties of carbon steel and stainless steel are both qualified, the corrosion resistance is excellent by electrochemical analysis and the intergranular corrosion test. At the same time, the welding performance of the clad plate is excellent, and the welding joint has good toughness and well corrosion resistance also in the case of reasonable welding process.

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