Development of S22053+12MnNiVR rolled clad steel plate for multi-stage flash desalination evaporator shell

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Abstract. This paper describes the development process of S22053+12MnNiVR composite steel plate using vacuum electron beam welding technology and double-sided symmetrical billet assembly method in ANSTEEL Co., Ltd., which has a product thickness of 2+12mm and is used in multi-stage flash seawater desalination evaporator shell. The stainless-steel clad steel plate has excellent comprehensive mechanical properties, good resistance to intergranular corrosion and seawater corrosion. The bonding rate of its composite interface meets the requirements of GB/T 8165-2008 Class I, and the bonding rate between atoms is 100%. As a new generation of green composite material, the successful development of S22053+12MnNiVR stainless steel-clad steel plate is of great significance in reducing the cost of seawater desalination, increasing the life of seawater desalination equipment, and realizing the localization of equipment, which provides an important way for China to solve the shortage of fresh water resources and lays a solid foundation for China to realize the green recycling of seawater resources.

1.Introduction
S22053 duplex stainless steel has excellent stress corrosion resistance, pitting corrosion resistance and crevice corrosion resistance under typical extreme environments, and can improve the corrosion resistance and service life of seawater desalination devices. Therefore, it becomes an ideal manufacturing material for evaporator shells [1]. However, the production cost of pure stainless-steel medium and heavy plates is relatively high, which is not conducive to the large-scale production of seawater desalination devices. ANSTEEL Co., Ltd. combined with the existing level of process equipment and production capacity, using vacuum electron beam welding technology and double-sided symmetrical billet assembly method, successfully developed a carbon steel with good mechanical properties of the same strength level and excellent corrosion resistance. S22053+12MnNiVR composite steel plate is used for the shell of the first-level flash desalination evaporator. Compared with traditional duplex stainless-steel medium and heavy plates, the price advantage of stainless-steel composite plates is obvious, which is of great significance for cost control and large-scale applications in seawater desalination devices.

2.Materials and Methods

2.1Chemical Composition
The chemical composition of 12MnNiVR shall meet the requirements of GB/T 19189-2011 and the chemical composition of S22053 shall meet the requirements of GB/T 4237-2015.
Table 1 Chemical composition of 12MnNiVR, S22053 (Wt%)

|        | C     | Si    | Mn    | P    | S    | Ni    | Cr    | Mo    | Cu    | V    | B    | N    |
|--------|-------|-------|-------|------|------|-------|-------|-------|-------|------|------|------|
| 12MnNiVR | ≤0.150| 0.40  | 1.60  | ≤0.020| ≤0.02-| ≤0.15-| ≤0.40 | ≤0.30 | ≤0.06 | ≤0.0020| -    |
| S22053  | ≤0.030| 1.00  | 2.00  | ≤0.030| ≤4.5- | 22.0- | 6.5   | 23.0  | -     | -    | 0.14-| -    |

2.2 Mechanical Properties

The mechanical properties of composite steel plate shall meet the requirements of GB/T 8165-2008, the inspection direction shall be transverse, and the inspection position shall be the full thickness of steel plate.

Table 2 Mechanical properties of S22053+12MnNiVR

|        | Tensile strength at room temperature | Impact at -20°C | Bending | Shear strength |
|--------|------------------------------------|-----------------|----------|----------------|
|        | Rm/ MPa                            | Kv/ J           | δ=2a     | τ/MPa          |
|        | ≥490                               | ≥18             | ≥100     | ≥210           |

2.3 Delivery status and inspection requirements

Solid solution heat treatment + pickling + passivation should be carried out before obtaining S22053 duplex stainless-steel billet. The upper and lower two sub-boards after the division are required to be ultrasonically inspected according to the NB/T47013.1-2015 standard, and the qualified level should be TI level.

2.4 Production process route

ANSTEEL Co., Ltd. adopts the symmetric billet method + vacuum electron beam welding technology to roll the S22053+12MnNiVR composite steel plate with a thickness of 2+12mm for the shell of the multistage flash seawater desalination evaporator. The production process is shown in Figure 1.

Fig 1 Production process flow chart

2.5 Symmetric billet assembly process

The symmetrical composite billet uses quenched and tempered high-strength steel 12MnNiVR as the base material, and duplex stainless steel S22053 as the composite material. After the size is determined, each layer of the board is finely polished with a drilling and milling machine to make the surface of the board have a uniform roughness, and this step also has a surface derusting effect. After polishing, the surface of the board is repeatedly cleaned with alcohol and acetone to remove oil stains, iron shavings and other attachments. Then, each layer of the plates is arranged in a four-layer symmetrical arrangement, and a high-temperature release agent is added between the two layers of S22053 to
facilitate the cutting and separation of the plates after rolling and forming. The high-temperature release agent is evenly sprayed on the surface of the stainless-steel cladding, and center the top and bottom to complete the billet assembly [2].

2.6 Vacuum electron beam welding process
The composite continuous casting billet is welded in a vacuum chamber. The pressure in the vacuum chamber must reach a high vacuum state below 1Pa. By creating a high vacuum environment, the problem of interface oxidation pollution during the later hot rolling process can be effectively solved to ensure the interface bonding of the composite steel plate rate. The entire vacuum welding process needs to be carried out under argon protection. The two laser welding heads need to be welded in opposite directions along the two parallel sides to complete multiple passes until the four sides of the composite billet are welded.

2.7 Rolling process
After the billet is taken out of the furnace, it is descaled by descaling box, and then descaled by high-pressure water again before rolling, which purpose is to remove the primary and secondary scales on the surface of the slab to ensure the surface quality of the steel plate. TMCP two-stage rolling is adopted, the initial temperature is ≥1050°C. The first-stage adopts rapid high-reduction rolling, the single-pass reduction rate of the first three times is ≥15%. The austenite grain refining degree increases in this process, and the ferrite grain after transformation is also refined. At the same time, the roller has a higher temperature after the first three times of rolling, so in the subsequent rolling process, the plate loses less heat through contact with the roller. In addition, the heat generated by plastic deformation itself lengthens the duration of the composite interface in the high temperature rolling stage, providing sufficient energy for refining the stainless-steel grains and sufficient diffusion energy and time for the alloy elements at the interface to ensure the good bonding of the composite interface [3]. Without rolling in the crystallization zone, the grain of the base carbon steel plate is further refined, so that the base steel plate has a good strength and toughness match, and can promote the remaining small unbonded zone at the composite interface to complete welding, to ensure that the bonding rate of the composite interface reaches 100%.

3. Results & Discussion

3.1 Mechanical properties and analysis

| Table 3 Mechanical properties of S22053+12MnNiVR |
|-------------------|--------------|-------------|-------------|----------------|---------------|--------|------------|
|                  |                |             | Impact at -20°C | Bending b=2a 180° | Shear strength | Interface binding rate | Flaw detection |
|                  | Rel/ MPa       | Rm/ MPa     | KV J          | Inward d=2a      | outward d=2a   | τ/MPa  | 100%       |             |
| Results          | 544            | 651         | 21.3          | 211              | 234           | 226    | qualified  | qualified  |
| Standard         | ≥490           | 610~730     | ≥19           | ≥100             | No crack      | No crack| ≥210       | I           |

It can be seen from Table 3 that the clad steel plate has good mechanical properties. Among them, the shear strength value, as an important index to characterize the bonding quality of the composite steel plate composite interface. A good interface bonding rate is the key to ensuring the shear strength and flaw detection results. During the tensile-shearing process of the shear specimen, the unbonded area at the interface will not cause stress concentration and induce the fracture morphology to appear as flat brittle cracks. But as the tensile-shearing process progresses, the shear force is uniformly transferred from the composite layer to the base layer through the composite interface, and the final shear fracture is located in the base layer. Before the fracture, the organization first undergoes the
plastic deformation stage, and finally because the shear strength is greater than the tensile strength of the material itself, the grain around the fracture is elongated. This is caused by the material itself hindering the occurrence of deformation. A large amount of carbon compounds can be found at the fracture, indicating that the interface bonding strength of the composite plate is relatively high [4].

3.2 Steel plate resistance to intergranular corrosion
The steel plate is sampled for sensitization treatment, the process is 675 °C. When the set temperature is reached, the sample is put into the furnace. After 1h of net heat preservation, the sample is cooled to room temperature with water, and then the steel plate is subjected to the intergranular corrosion test by ASTM A262-2015 standard E method. Observing the surface of the 180° curved sample under the microscope 10 times and observing the microstructure of the bending position under the metallographic microscope 50 times, no cracks and microscopic intergranular corrosion induced by intergranular corrosion were found, indicating that the intergranular corrosion resistance of the composite steel plate is good.

![Stereomicroscope photos](image1)
![Metallographic photograph](image2)

Fig.2 Bending photos of intergranular corrosion specimens

3.3 Corrosion performance of steel plate with high temperature and high concentration seawater
Based on the JB/T 7901-2001 standard, the composite plate multi-layer S22053 stainless steel is subjected to high temperature and high concentration seawater corrosion performance evaluation test. The simulated test environments are room temperature, 70°C, and 90°C 10% NaCl aqueous solution, and the test results are shown in Figure 3 and Figure 4.

![Corrosion kinetics curve](image3)

room temperature

70°C

90°C

Fig.3 Corrosion kinetics curve of etched sheet in 10% NaCl aqueous solution at different temperatures
Figure 3 shows that in a 10% NaCl environment, at room temperature, 70°C, and 90°C, after 4W (672h) corrosion test period, the most serious weight loss is the corroded sheet in an environment of 90°C, and its weight reduction ratio before and after the corroded sheet is about 1‰. From the photo of the sample after 4W (672h) immersion corrosion in Figure 4, it can also be seen that there is no obvious corrosion product and corrosion crack formation on the surface of the corrosion sheet, and the surface is still relatively smooth and bright.

The reasons for duplex stainless steel has good corrosion resistance in seawater are as follows: (1) The cause of corrosion cracking is that the passive film on the surface of the stainless-steel slips and is destroyed, causing the corrosive medium to be directly connected to the substrate. Compared with the single-phase austenitic stainless steel, the ferrite + austenite two-phase structure of duplex stainless steel has a higher yield strength, that is, under the same corrosive environment, the critical stress required for the surface slip of dual-phase stainless steel is higher, which is difficult to cause the coarse slip, and the surface corrosion cracking is difficult to form. (2) Ferrite has an electrochemical protective effect on austenite. Due to the different corrosion electrode potentials of the two-phase structure of duplex stainless steel, the expansion mechanism of corrosion cracking at different phases and phase boundaries is also different, which effectively prevents or inhibits the propagation of cracks, and the generation of corrosion cracks is very slow. (3) S22053 duplex stainless steel contains a higher content of chromium and molybdenum elements. The addition of these elements can make the stainless steel have better pitting corrosion resistance, inhibit the expansion of the connection between pitting points, and prevent the generation of corrosion crack source. (4) The two-phase structure of duplex stainless-steel acts as a mechanical barrier to each other during the propagation of corrosion cracks, thereby preventing the possibility of continuous crack propagation. In addition, due to the different crystal shapes and orientations of the two-phase structure, the cracks frequently change their directions during the propagation process, which greatly extends the growth period of corrosion cracks and is not easy to cause transcrystalline corrosion\[5\,6\].

3.4 Macroscopic and metallographic structure of steel plate
The metallographic structure observation of the fusion line position of the composite plate was sampled for micro-observation, and the results are shown in Figure 5.
The metallographic photo shows that the metallographic structure of the composite layer S22053 is austenite + ferrite, and the metallographic structure of the base layer 12MnNiVR is mainly composed of recrystallized ferrite and aggregated cementite to form a bainite tempered structure. Compared with the position close to the center of the base layer, the carbide aggregation distribution in the composite interface position is more obvious, and there is a certain proportion of ferrite structure. This is because there is a gradient distribution of multiple elements at the bonding interface position of the composite plate sample. Under the action of element concentration difference, the interaction diffusion of C, Cr, Ni and other elements occurs at the interface. The carbon element in the base carbon steel diffuses to the composite layer, forming a decarburization layer in the composite interface base. Cr and Ni diffuses to the base layer, and combines with the C element in the base layer to form stable carbides. At the same time, a chromium-poor layer is formed in the lamination of the composite interface, and the interaction and diffusion of elements ensure the good combination of the composite interface\(^7\text{-}^8\).

4. Conclusions

(1) The S22053+12MnNiVR composite steel plate produced by ANSTEEL Co., Ltd. has a good match of strength and toughness, the bonding rate of the composite interface meets the requirements of GB/T 8165-2008 Class I, and the application performance meets the requirements of equipment manufacturing;

(2) The S22053+12MnNiVR composite steel plate produced by ANSTEEL Co., Ltd. has good intergranular corrosion resistance and seawater corrosion resistance, meeting the long-term service requirements as a shell material in the special environment of multi-stage flash desalination evaporators;

(3) The S22053+12MnNiVR composite steel plate produced by ANSTEEL Co., Ltd. has good overall performance and can be used as the raw material for the production of seawater desalination equipment to manufacture multi-stage flash desalination evaporators.

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