Cause Analysis of Leakage in 316L Stainless Steel Heat Exchanger

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Abstract. A large area of leakage occurred in plate heat exchanger of a power plant. The causes of leakage were analyzed by means of appearance analysis, chemical composition analysis, microstructure detection and energy spectrum analysis. The results show that Cl ion exists in the environment of the leaking heat exchanger, which has strong corrosiveness to austenitic stainless steel. At the same time, there are machining residual stress and internal stress produced by internal medium in the heat exchanger, which lead to stress corrosion and cracking.

1. Introduction
Austenitic stainless steel is widely used in power plant equipment manufacturing because of its excellent corrosion resistance and high temperature oxidation resistance. However, in the corrosive medium containing Cl, austenitic stainless steel is prone to stress corrosion brittle cracking [1,2]. There are many factors that affect the stress corrosion of stainless steel, such as temperature, pressure, stress level, chloride system and concentration, pH value, steel type and heat treatment process, welding[3,4]. Understanding the mechanism of stress corrosion of stainless steel and taking corresponding measures can effectively guarantee the safe and stable operation of the equipment.

During the disassembly and inspection of plate heat exchanger in a power plant, it was found that there were wear, corrosion pits and pockmarks on the heat exchanger plates. Then the hydraulic test of the heat exchanger was carried out, and a large area of leakage was found. The heat exchanger is made of 316L stainless steel.

2. Test method and result analysis
2.1. Macromorphology analysis
Through the macromorphology inspection of the leaking heat exchanger, it is found that there are a lot of pitting corrosion on the steel plate of the heat exchanger, as shown in Figure 1.
2.2. Chemical composition analysis

The chemical composition of the leaking heat exchanger samples is analyzed, and the results are shown in Table 1. The results show that the chemical composition of the sample meets the requirements of the standard.

| Element | C   | Si  | Mn  | Cr  | Ni  | Mo  | P  | S  |
|---------|-----|-----|-----|-----|-----|-----|----|----|
| GB 24511-2009 | 0.37~0.44 | 0.17~0.37 | 0.50~0.80 | 16.00~18.00 | 10.00~14.00 | 2.00~3.00 | ≤0.035 | ≤0.035 |
| Measured value | 0.40 | 0.22 | 0.65 | 17.11 | 12.22 | 2.44 | 0.007 | 0.019 |

2.3. Microstructure analysis

The microstructure of the leaking heat exchanger is observed as shown in Figure 2. The matrix structure is single-phase austenite with a large number of twins, and there is no large amount of precipitates and aging phenomenon. There are many microcracks, the main crack is like the trunk, and the interior is full of corrosion products. Most of the cracks are transgranular with a lot of branches. It has typical stress corrosion cracking characteristics of austenitic stainless steel.

2.4. Energy spectrum analysis

The energy spectrum analysis of the material contained in the microcrack is carried out, and the results are shown in Figure 3. The results show that there are corrosion products containing Cl at the crack tip, while the stress corrosion cracking of stainless steel is often related to the corrosive Cl - in the contact medium.
3. Results and discussion

Metal corrosion is a process of chemical or electrochemical interaction between metal and surrounding medium. The environment where the metal is located contains corrosive substances, which are very easy to cause metal corrosion. Moreover, the corrosion process of metal is the process of metal oxidation. In chemical corrosion, metals are oxidized and corrosives are reduced, and oxidation-reduction reaction takes place between metals and corrosives through direct transfer of electrons. In electrochemical corrosion, oxidation reaction and reduction reaction are independent, and electron transfer is indirect. Therefore, electrochemical corrosion is more common and complex [5]. Stress corrosion cracking is the most common occurrence of metal in wet corrosion environment. Stress corrosion cracking is a kind of cracking failure that occurs under the joint action of tensile stress and corrosion medium [6].

The contact between stainless steel and medium does not always lead to stress corrosion, and stress corrosion cracking will occur only in specific corrosion environment. Austenite is easy to produce stress corrosion in Cl- environment. There are corrosion products of Cl in the cracks of the heat exchanger, which form the environmental conditions of stress corrosion. In addition, a multi slit structure is formed after the plate is assembled, such as the contact between the plates, the bottom of the sealing groove and other parts. When the scale on the surface of the plate is serious, the corrosive elements (Cl, S, etc.) in the medium attach to the scale, and accumulate in the bottom gap of the scale, which is easy to cause the crevice corrosion at the contact. At the same time, the residual stress produced in the process of equipment manufacturing or welding and the stress caused by working load is another condition that causes stress corrosion of heat exchanger.

The shape of stress corrosion crack is mostly in the form of dead tree branch, which develops along the vertical direction of tensile stress. The micro shapes are transgranular, intergranular and mixed. Chloride ion can cause both pitting corrosion and stress corrosion cracking of stainless steel. The critical temperature of chloride ion stress corrosion cracking is 70 °C, which can occur not only on the inner wall of equipment, but also on the outer wall of equipment and pipeline. This kind of crack is a typical transgranular crack [7,8]. There are a lot of dendritic cracks and many microcracks in the heat exchanger steel plate. Most of the cracks are transgranular and have a lot of branches, which have typical stress corrosion cracking characteristics of austenitic stainless steel.

4. Conclusions and suggestions

According to the above analysis, the main causes of the leakage of the heat exchanger are as follows: the heat exchanger contacts the medium containing corrosive Cl-, which destroys the solid, fine and stable chromium rich oxide film on the surface of stainless steel; at the same time, stress corrosion cracking occurs under the long-term action of residual stress and tensile stress caused by internal medium.
Three factors related to stress corrosion are material, tensile stress and environment. Materials include steel, sensitivity and fatigue; stress includes residual stress, working stress, concentrated stress and alternating stress; environment refers to corrosion medium. The occurrence of stress corrosion can be prevented by eliminating any of the three factors [9].

Therefore, the crevice corrosion at the plate contact can be effectively prevented by selecting materials correctly, assembling correctly, cleaning regularly to destroy the formation conditions of corrosion and reducing the content of harmful ions such as chloride ion in the medium. Titanium is the best structural material to resist pitting corrosion and crevice corrosion [10]. Stainless steel plate can be replaced with titanium plate when conditions permit, so as to avoid similar failure again. At the same time, it is suggested to find out the cause of the plate heat exchanger contacting the corrosive medium and replace the leaking plate heat exchanger in time.

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