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Crack Failure Analysis of Stainless Steel Seamless Pipe

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Abstract. Stainless steel pipe is widely used in machinery manufacturing industry, mainly used as steam, liquefied natural gas, natural gas, various petroleum products transmission pipeline. China is the largest consumer of stainless steel tube in the world, and in recent years the total consumption of stainless steel accounted for more than 20% of the total consumption in the world. Stainless steel pipe has good mechanical properties and good corrosion resistance, so it is widely used in the ocean engineering and shipbuilding industry, which is widely used in offshore oil and gas fields, deep water pumps, offshore drilling platforms, seabed mining devices, warships and other aspects. In this paper, the leakage of stainless steel seamless steel pipe used by a company is studied to discuss the failure behavior of stainless steel seamless steel pipe. The microstructure analysis shows that the fracture surface has the characteristics of stress corrosion crack. Chemical composition analysis, chemical composition of the sample GB/T 13296-2013 "Seamless Stainless Steel Tubes for Boilers and Heat exchangers" requirements for S31708 stainless steel; SEM and EDS detection: the corrosion products of seamless steel pipe fracture and the scale composition in the tube were detected. The corrosive medium Cl was found in the scale composition detection, and no obvious corrosive medium was found in the corrosion products of the fracture surface

Keywords. Stainless steel seamless pipe, microstructure, chemical composition, stress corrosion

1. Introduction

Stainless steel seamless steel pipe is a kind of long steel with hollow section and no weld around it. It has the chemical stability of water, steam, air and other corrosive media and acid, alkali, salt and other corrosive media. It is often called stainless acid resistant steel pipe [1-5]. Stainless steel seamless steel pipe has the advantages of high strength, high pressure, mechanical structure and other aspects, widely used in petrochemical, food, medical, mechanical instrument and other mechanical structural parts and chemical pipeline transportation. However, in the use of stainless steel seamless pipe, cracks often occur due to corrosive medium, stress concentration and external tensile stress, resulting in failure [5-7].

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In this paper, the failure behavior of stainless steel seamless steel pipe is discussed through the crack of stainless steel seamless steel pipe used by a company. It is understood that in the process of operation found stainless steel seamless pipe leakage, use time 2200 hours, in the steel pipe welding area found a longitudinal crack, in addition, in the same pipe in another place found a transverse crack. A large amount of scale was found in the inner wall of the seamless stainless steel pipe. According to the feedback information, the crack failure of stainless steel seamless pipe is analyzed.

2. Overview

The macroscopic morphology of stainless steel seamless steel pipe is shown in figure 1. A longitudinal crack was found at the weld of stainless steel seamless pipe.

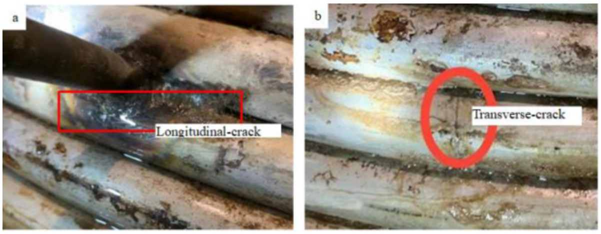

Figure 1. Macro drawing of stainless steel seamless pipe.

As the internal working temperature of the pipe wall is 184℃, which is relatively high, the pipe will expand and deform during operation, and there will be great tensile stress on the outer surface of the circumferential pipe. At the same time, because the pipe is circumferential winding arrangement, the inner surface of the pipe bears compressive stress, while the outer surface bears tensile stress. Stress corrosion is the joint action of tensile stress and corrosive medium. Therefore, the cracks in the figure crack on the outer surface.

3. Experimental Analysis and Results

3.1. Analysis of Fracture Morphology

The crack was opened, and the stainless steel seamless tube fracture was observed by electron microscope (SEM) after rust removal and decontamination, as shown in figure 2. Many cracks were found in the inner wall, the cracks were diffused around, discontinuous, local extension, quasi-cleavage fracture. Cleavage crack nuclei are generated in different places and expand into cleavage plane. The river grain is short and curved, the cleavage plane is small and there are many tearing edges around.

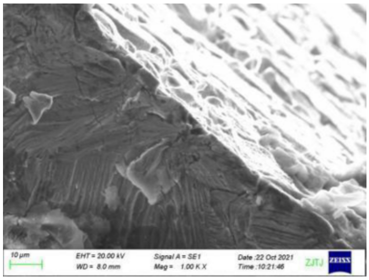

Figure 2. SEM of fracture of stainless steel seamless tube.

3.2. Metallographic Microstructure

Metallographic inspection was conducted on the grinding, polishing and corrosion of stainless steel seamless tube, as shown in figure 3.

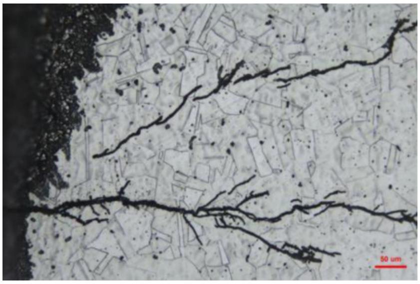

Figure 3. Metallographic photo of stainless steel seamless pipe.

As shown in figure 3, the microstructure of the stainless steel seamless tube is austenite, and there are transgranular and intergranular mixing cracks on the surface of the material. On the surface of the fracture, the cracks are disordered, and the cracks mainly spread from the inner wall to the middle, and a lot of pitting corrosion occurs near the inner wall. Main features: cracks or even fractures occur, and the origin of cracks is usually at the bottom of pitting corrosion holes or pits. The crack propagation is intergranular and transgranular mixed type. The main crack is perpendicular to the stress direction and has branches, and the crack ends are sharp. Under the combined action of stress and corrosive medium, the brittle cracking phenomenon below the material strength limit appears after a period of time, resulting in the failure of metal materials, that is, stress corrosion cracking.

3.3. EDS Detection

According to the inspection scheme, the stainless steel seamless tube was analyzed by energy dispersive spectroscopy (EDS). A small amount of corrosive medium Cl was found in the scale component detection, and no obvious corrosive medium was found in the surface corrosion product detection of the fracture, as shown in figure 4.

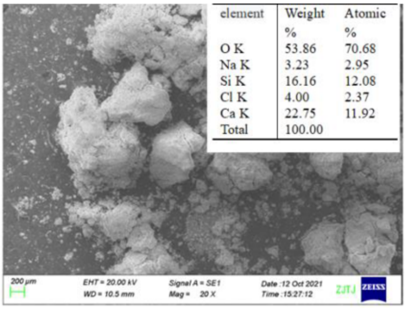

Figure 4. EDS detection of corrosion products.

The sample was ground, polished, etched, and further observed using an electron microscope, as shown in figure 5. The SEM image is consistent with the metallographic image, which shows that the crack is formed by the pitting corrosion on the inner wall of the tube, and the crack expands to the middle, resulting in the material cracking. Stress corrosion cracking (SCC) is the result of the interaction of stress, environment and material. The main sources of stress are the working stress imposed on the material and the residual stress generated in the machining process [7-8]. SCC occurs in acidic, alkaline, high-temperature water and so on. In addition, stainless steel exhibits high stress corrosion sensitivity when the environment contains certain ions, especially chloride ions. In addition to stress and environment, the composition of materials, microstructure and heat treatment process also have different influences on the stress corrosion of stainless steel [7-8].

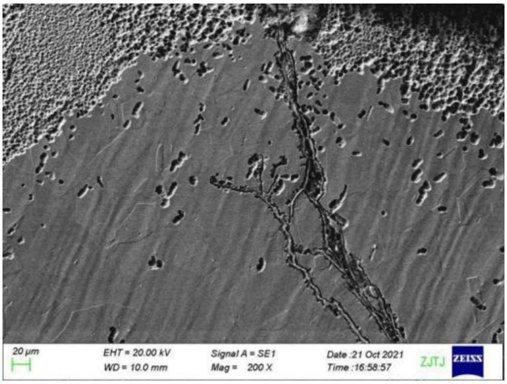

Figure 5. Electron microscope image of crack.

3.4. Microhardness

In the microhardness test, the average hardness values of the front and side of the longitudinal crack are $HV_{10}173$ and $HV_{10}178$ respectively, the average hardness values of the front and side of the transverse crack are $HV_{10}166$ and $HV_{10}159$ respectively, and the average hardness values of the longitudinal and transverse surface of the no-crack area are $HV_{10}169$ and $HV_{10}174$ respectively, which meet the product requirements. As shown in table 1.

Table 1. Microhardness values.

Type	Location	Hardness (HV10)			Average
Longitudinal crack	The crack front	175	174	170	173
	Crack on the side	178	181	176	178
Transverse cracks	The crack front	163	168	168	166
	Crack on the side	156	163	158	159
Normal area	Horizontal plane	160	169	179	169
	The vertical plane	173	176	173	174

3.5. Chemical Composition Detection

According to the inspection plan, the chemical composition of stainless steel seamless tube was tested. The chemical composition of S31708 stainless steel conforms to GB/T 13296-2013 standard, as shown in the following table 2.

Table 2. Chemical composition detection.

Element	C	Si	Mn	P	S	Cr	Ni	Mo
Acceptable range(%)	≤0.08	≤1.00	≤2.00	≤0.035	≤0.030	18.00-20.00	11.00-15.00	3.00-4.00
The readings	0.02	0.37	0.74	0.0313	0.001	18.27	11.66	3.15

4. Results and Analysis

According to the test results, the inner wall of stainless steel pipe found many crack sources, crack sources to diffuse around, discontinuous, local expansion, the fracture form of quasi-cleavage fracture. The microstructure of the material is austenite and there are intergranular and transgranular cracks on the surface of the material. On the surface of fracture, the cracks are disordered. On the fracture side, the cracks mainly spread from the inner wall to the middle, and a lot of pitting corrosion occurred near the inner wall. Corrosive medium Cl was found in scale composition detection, and no obvious corrosive medium was found in fracture surface corrosion products detection. No stress corrosion cracks were detected after intergranular corrosion, and no cracks were found in the inner and outer walls after bending test.

To sum up, the cause of crack is stress corrosion. As the inner working temperature of the pipe wall is 184°C, the temperature is relatively high, and the pipe will expand and deform during operation, and the outer surface of the annular pipe will have great tensile stress. Meanwhile, because the pipe is torally wound, the inner surface of the pipe bears compressive stress, while the outer surface bears tensile stress. Stress corrosion is under the joint action of tensile stress and corrosive medium. In the seamless stainless steel tube wall first by the spot corrosion, the formation of cracks, cracks to the middle expansion, resulting in material cracking. According to the test results, there is more scale in the inner wall of the pipe where the stress corrosion is serious, and there is serious stress corrosion in the welding area. No obvious stress corrosion is detected in the area where the scale is less. Therefore, there are two main reasons for stress corrosion: one is the corrosive medium, the other is the residual stress.

There are many small corrosion pits in the crack area, in which local stress concentration is easy to occur and stress corrosion sensitivity is greatly increased. Microcracks are initiated in such pitting pits. Pitting pits are numerous and clustered, and the cracks propagate along the traces linked together by many small pitting pits. The reason for pitting is that there are active anions (Cl ions) in the service environment. With the increase of ion concentration, the breakdown potential moves negatively and pitting is easy to occur. In addition, the grain boundary is prone to pitting due to the uneven adsorption and structure of grain boundary. The generation of stress will cause dislocation structure in stainless steel, and dislocation in the surface of the outcrop is easy to produce pitting, once pitting pit is formed, there will be stress concentration in the front of the pitting pit. First, stainless steel tube medium 1.0mpa /184℃ soda mixture, steam dryness 75%, the existence of pressure, the circumferential stress by the tube is tensile stress, second, there is the presence of Cl ion, third, because the tube wall working temperature is 184℃, the temperature is higher, The austenitic stainless steel pipe produces stress corrosion under the simultaneous action of these aspects [7-8]. Weld stress analysis, weld in the operation of equipment, mainly by the work stress and residual stress. The residual stress of equipment in the process of welding, processing and assembly is the main factor, especially the weld, because of the density of the weld, the failure caused by the residual stress of the weld.

Acknowledgement

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