Corrosion Behavior of 316L Stainless Steel Weld under Constant Strain

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Abstract. 316L stainless steel is widely used in the fields of thermonuclear industry and petrochemical industry due to its excellent comprehensive mechanical properties and corrosion resistance. Especially in the petroleum industry, 316L stainless steel is commonly used as oil pipelines and storage tanks because of its high corrosion resistance to media such as CO₂. However, Petroleum and natural gas generally contain corrosive media, such as high concentrations Cl⁻, CO₂, H₂S. When petroleum pipelines work in such a strong corrosion environment for a long time, pitting corrosion or stress corrosion cracking is easy to occur, and these corrosion behaviors preferentially occur in defects such as welds and heat-affected zones. Therefore, in order to ensure the safety and durability of oil and gas export process, it is necessary to study the stress corrosion cracking sensitivity of oil and gas pipeline, especially the stress corrosion sensitivity of oil and gas pipeline weld seam, heat affected zone and other defects. the paper uses three-point bending loading method, and the corrosion morphology of the sample is analyzed by optical microscope. Researching 316L stainless steel weld corrosion behaviors under constant strain.

1. Introduction
With the rise of petroleum and chemical industry in China, the transportation distance of oil and natural gas is increasing, which requires oil and gas pipelines to have good mechanical properties. However, Petroleum and natural gas generally contain corrosive media, such as high concentrations Cl⁻, CO₂, H₂S. When petroleum pipelines work in such a strong corrosion environment for a long time, pitting corrosion...
or stress corrosion cracking is easy to occur, and these corrosion behaviors preferentially occur in defects such as welds and heat-affected zones\cite{1-3}. Therefore, in order to ensure the safety and durability of oil and gas export process, it is necessary to study the stress corrosion cracking sensitivity of oil and gas pipeline, especially the stress corrosion sensitivity of oil and gas pipeline weld seam, heat affected zone and other defects.

Currently, there are many methods to study the corrosion behavior of stainless steel composite pipe weld, this chapter uses the three-point bending load method to study the corrosion behavior of 316L stainless steel welds under constant strain conditions. The advantages of this method are mainly that the loading tool is simple, economical and easy to operate, and the sample can be taken out for observation at any time, moreover, long-term experiments can be carried out in batches for simple and small samples.

2. Test method and equipment

2.1 Test materials
the test material is 316L stainless steel, it is an austenitic stainless steel from the point of view of the metallurgical organization, the standard grade of our country is 022Cr17Ni12Mo2. The specific chemical composition is shown in table 1, and the mechanical properties of 316L stainless steel are shown in table 2.

| Element | C   | Cr  | Mn  | Ni  | Si  | P   | S   | Ti  | Fe   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|------|
| percent | 0.097 | 17.75 | 1.19 | 9.31 | 0.53 | 0.03 | 0.0064 | 0.56 | allowance |

| Mechanical property | Tensile strength (MPa) | Yield Strength (MPa) | Elongation rate (%) |
|---------------------|------------------------|----------------------|---------------------|
| Index               | 660                    | 360                  | 30                  |

2.2 Test equipment
In this paper, the three-point bending loading method is used to study the corrosion behavior of 316L stainless steel welds under constant strain conditions. The test fixture is a self-designed device according to the experimental requirements. In order to avoid galvanic corrosion of the equipment and samples, it is made of 3D printing photosensitive resin, which has suitable strength and good insulation. Three-point bending device mode is shown in figure 1.

![Fig.1 Three-point bending device mode](image_url)
2.3 Sample preparation method

The sample used is a new type of non-standard small sample, which can be used to evaluate the stress corrosion sensitivity of thinner plates, and it also has the characteristics of easy operation and simple equipment requirements. The sample size is 30mm×3mm×1.5mm (length×width×height), and its schematic diagram is shown in figure 2. Before the test, firstly, the sample is notched, that is, a 1mm×1mm (length×width) notch is cut by wire cutting in the weld area and fusion line of the sample, the schematic diagram is shown in Figure 3, its purpose is mainly to shorten the stress corrosion cycle, but also to reduce the reproducibility of the measured data, which is conducive to the measurement of certain parameters such as crack growth rate. Secondly, the sample was polished step by step with metallographic sandpaper 180#,400#,800#,1500#, cleaned with acetone, and then the sample was blown dry with hair dryer.

![Fig.2 Schematic three-point bend specimen](image1)

![Fig.3 316L stainless steel pre-cracked specimens schematic diagrams](image2)

1- weld zone; 2- heat affected zone; 3- base metal; 4- afterburner point; 5- anchor

3. Metallographic organization analysis

The connection method of 316L stainless steel composite pipe is mainly TIG welding, the observation of weld structure is one of the important means to study the corrosion behavior of weld. The sample was polished step by step with metallographic sandpaper 180#,400#,800#,1500#, then, place the sample on the polishing machine for polishing, and select oxalic acid with a concentration of 10% to electrolytically corrode the sample, the current is controlled at about 0.5A, and the electrolysis time is about 1min, finally, the microstructure of the base metal and weld of the sample are observed through an optical microscope. Figure 4 shows the low-magnification morphology of the weld. It can be seen in the figure that the weld zone can be divided into weld, heat-affected zone and base metal. In this article, it is calibrated as zone 1, 2, and 3. Figure 5 shows the metallographic structure at the center of the weld (1 in figure 4), figure 6 shows the metallographic structure in the heat-affected zone (2 in figure 4), and figure 7 shows the metallographic structure of the base metal (3 in figure 4).
Figure 4 shows the weld morphology: (1) weld, the weld width of about 450mm; (2) the heat-affected zone, HAZ width approximately 100mm; (3) the base material.

Figure 5 shows that the microstructure at the center of the 316L stainless steel weld is ferrite + austenite, and the ferrite is intermittently distributed on the austenite matrix. Because the solidification process of the 316L stainless steel weld is firstly that ferrite crystallizes out of the liquid. The precipitated ferrite then reacts with the liquid phase to form austenite through peritectic reaction, and the austenite is attached to the ferrite. Nucleate and then grow up around ferrite. Therefore, in addition to the austenite formed by the inclusion reaction, there are ferrite residues surrounded by austenite, and the ferrite is uniformly distributed on the austenite matrix, resulting in uneven grain boundaries, which makes the cracks in the weld difficult to propagate\(^{(4-5)}\).

It can be seen from figure 6 that figure (b) shows the metallographic structure near the weld fusion line. The microstructure is close to the two-phase structure of the weld, which is composed of austenite...
and strip ferrite. The side is composed of single austenite. Figure (a) is the microstructure of weld heat affected zone near fusion line, and figure (c) is the microstructure of weld heat affected zone near base metal. The grain size in figure (a) is obviously larger, and the structure in figure (c) is similar to that of the base metal, but it is obviously larger than the matrix grain size. This is because the higher the temperature of the microstructure in the heat affected zone near the fusion line, after the process of heating, the microstructure of the heat affected zone is coarsened and the grain size is larger.

![Fig.6 heat affected zone microstructure](image)

It can be seen from figure 7 that the metallographic structure of the base metal is mainly a single solid solution austenite, and the grain size distribution is relatively uniform. Which 316L stainless steel is an ultra-low carbon austenitic stainless steel with good machining performance and welding performance. The chromium element is not easy to precipitate and form chromium carbide compound with the carbon element because of the low carbon content. Therefore, its also has good corrosion resistance.
4. Corrosion behavior of weld

This section mainly studies the corrosion behavior of welds under different Cl\(^-\) concentrations. The corrosion solution is a NaCl solution with Cl\(^-\) concentration of 141480 ppm, 70740 ppm, 14148 ppm and 1% FeCl\(_3\), pH value of 1. Figure 8 shows the macro-corrosion morphology of 316L stainless steel composite pipe welded samples in NaCl solutions with different Cl\(^-\) concentrations. Figure 9 shows the microscopic corrosion morphology of 316L stainless steel composite pipe welded samples in NaCl solutions with different Cl\(^-\) concentrations.

It can be seen from figure 8 that by applying a certain force to the 316L stainless steel composite pipe welding sample and immersing it in the corrosive medium for a period of time, it is found that no matter the concentration of Cl\(^-\) in the corrosive solution is 141480 ppm, 70740 ppm, or 14148 ppm, the sample has more serious corrosion. Compared with the matrix, the weld and heat-affected zone are corroded more seriously. When the concentration of Cl\(^-\) in the solution was 141480 ppm, the surface of the weld and the heat-affected zone was corroded severely by naked eyes, and the weld part even showed a crow's feet-like appearance. When the concentration of Cl\(^-\) in the solution decreases, the surface of the sample still shows serious corrosion, but relative to the condition of the concentration of Cl\(^-\) being 141480 ppm, the degree of corrosion is weakened, especially when the concentration of Cl\(^-\) in the solution is 14148 ppm, the corrosion degree of the sample surface is obviously weakened. Finally, the sample was immersed in 10% nitric acid solution to remove the surface oxidation products, and there are no cracks appeared on the surface.
Fig. 8 316L stainless steel corrosion morphology of composite pipe welding samples in different Cl- concentrations of NaCl solutions

It can be seen from Figure 9 that the 316L stainless steel composite pipe welding sample by observing the microscopic corrosion morphology, it is shown that no matter the concentration of Cl\(^-\) in the corrosion solution is 141480ppm, 70740ppm, or 14148ppm, the surface of the sample has serious corrosion. The corrosion damage of weld and heat affected zone is more serious than that of base metal. It shows that the corrosion resistance of the weld and heat-affected zone is poor compared to the base metal under the condition of the same Cl\(^-\) concentration. In addition, microcracks appeared near the fusion line, showing obvious stress corrosion cracking characteristics.
Fig. 9 316L stainless steel microscopic morphology of composite pipe welding samples in different Cl- concentrations of NaCl solutions

It can be seen from figure 10 that the weight loss of 316 L stainless steel composite tube welded samples in different Cl- concentrations of NaCl solutions; When the Cl- concentration in the solution is 141480 ppm, the weight loss of the sample is 0.24 g; When the Cl- concentration is 70740 ppm, the weight loss of the sample is 0.2 g; When the Cl- concentration in the solution is 14148 ppm, the weight loss of the sample is 0.14 g. In a word, the weight loss of sample corrosion increases with the increase of Cl- concentration, that is, the corrosion resistance of 316L stainless steel welds decreases with the increase of Cl- concentration.

Fig. 10 316L stainless steel weightlessness of composite pipe welding samples in different Cl-concentrations of NaCl solutions
5. Conclusions

(1) The microstructure at the center of the 316L stainless steel weld is ferrite + austenite, and the ferrite is intermittently distributed on the austenite matrix. The metallographic structure near the weld fusion line is divided into two parts: a two-phase structure composed of austenite and strip ferrite on the side close to the weld, and a single austenite on the side close to the heat effect. The metallographic structure of the heat-affected zone is similar to that of the base metal, but the grain size of the matrix is significantly larger. The metallographic structure of the base metal is mainly single solid solution austenite, and the grain size distribution is relatively uniform.

(2) 316L stainless steel composite tube welded samples were immersed in different Cl− concentrations of NaCl solution. After a period of time, the samples were corroded seriously. With the increase of solution Cl− concentration, the surface corrosion degree of the samples increased. And compared with the matrix, the weld corrosion is more serious and the stress corrosion cracking occurs near the weld fusion line.

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