Influence of Residual Stress on the Corrosion Behaviors of Welded Structures in the Nature Seawater

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Abstract. The corrosion behaviors of X65 welded structures were investigated, aiming to achieve the influence of residual stress on the corrosion behaviors of welded structures in the nature seawater. Methods such as corrosion rate measurement and corrosion morphology observation were used in the research. The results indicated that high-level of residual stress could accelerate the corrosion damage of weld joint, HAZ, and parent metal of welded structures, but had little influence on the overall corrosion rate of welded structures. Under the influence of different level of residual stress, corrosion morphology evolution on the surface of weld joint, HAZ, and parent metal were different, and so did the corrosion characteristics of the different areas of welded structures. Compared to the weld joint and parent metal, area with the most serious corrosion damage generated in the HAZ at last. Therefore, the HAZ needs to be significant concerned while designing the corrosion failure prevention measures of the welded structures.

1. Introduction

Pipeline is the mainly transportation mode of offshore oil and natural gas, thus the security and service life of pipeline have been highly focused by researchers [1-3]. However, as the primary joining method of pipeline, welding will produce high level of residual stress in the welded pipe, and then decrease the corrosion resistance of pipeline [4-6]. Over the course of the study, the corrosion behaviors of welded structures are mainly researched through the analysis of electrochemical reaction on the surface of welded structures, while the investigation on the influence of residual stress on the corrosion behaviors of welded structures are few [7-10]. Due to the lack of research achievement, the design of corrosion failure prevention measures of welded structures is inconvenient.

In this paper, the corrosion behaviors of X65 welded structures in nature seawater were researched. Before the corrosion test, part of welded specimens were treated by vibratory stress relief (VSR), aiming to decrease the residual stress in specimens. Meanwhile, the corrosion rates and corrosion morphology evolution of welded specimens with different level of residual stress were analyzed. Therefore, the influence of residual stress on the corrosion behaviors of welded structures in nature seawater were achieved, and the achievement is significant to the design of corrosion failure prevention measures of welded structures.
2. Experiment

2.1. Specimens preparation
X65 steel was used in the experiment, and the dimensions of welded specimens were 350 mm × 150 mm × 10 mm. The welded specimens were divided into 6 groups during corrosion test, numbering A1-A6. Meanwhile, there were three welded specimens in each group. In order to reduce the residual stress in the specimens of group A1-A3, VSR method was imposed on the specimens of group A1-A3 before the corrosion test [11,12].

2.2. Seawater corrosion test
The seawater corrosion test was performed according to the Chinese national technique standard GB/T 6384-2008, and the corrosion test continued for 180 days. Natural seawater from the East China Sea was used in the test, whose major chemical components are listed in Table 1. The surface film of welded specimens was removed through pickling before the corrosion test, so as to exclude the effect of inconsecutive surface film on the corrosion behaviors of specimens. Meanwhile, graphite flake was connected with the welded specimen to constitute a galvanic cell structure during corrosion test, aiming to increase the corrosion rate of welded specimens in the nature seawater. While the corrosion time reached 60 d, 120 d, and 180 d, one group of specimens from both A1-A3 and A4-A6 were taken out, respectively. The corrosion morphologies of weld joint, heat affected zone (HAZ), and parent metal of specimens from groups with different corrosion time were observed, in order to investigate the evolution of corrosion morphologies on the surface of welded structures which is effected by different level of residual stress.

2.3. Corrosion rate measurement and corrosion morphology observation
After the specimens were taken out, the corrosion products on the surface of corroded specimens were removed by H₂SO₄ solution. Meanwhile, corrosion inhibitor of thiourea was added while pickling to protect the base material.

In order to analyze the corrosion rates of corroded specimens in different corrosion time, the mass of specimens before and after corrosion were measured respectively, and the measurement should reach a precision of 0.01g. Meanwhile, the corrosion morphologies on the surface of weld joint, HAZ, and parent metal of corroded specimens were observed with scanning electron microscope (SEM), and the corrosion characteristics in different areas of corroded specimens were analyzed.

3. Results and discussion

3.1. Corrosion rate
The corrosion rates of specimens with different level of residual stress were calculated, aiming to research the influence of residual stress on the corrosion rate of welded structures. The computational formula is shown as Equation (1) [13].

\[ v = \frac{(m_0 - m_t)}{(s \cdot t)} \]  

(1)

where \( v \) : corrosion rate of specimen; \( m_0 \) : mass of uncorroded specimen; \( m_t \) : mass of corroded specimen; \( s \) : superficial area of specimen, and \( t \) : corrosion time.

The calculated results of corrosion rates of welded specimens with different level of residual stress in different corrosion time are shown in Table 2.
Table 2. Calculated results of welded specimens in different corrosion time.

| Corrosion time | Serial number of specimens | Average corrosion rate [g/(m²·h)] | Vibratory stress relief |
|---------------|-----------------------------|-----------------------------------|------------------------|
| 60d           | Group A1                    | 0.166                             | Yes                    |
|               | Group A4                    | 0.164                             | No                     |
| 120d          | Group A2                    | 0.109                             | Yes                    |
|               | Group A5                    | 0.111                             | No                     |
| 180d          | Group A3                    | 0.095                             | Yes                    |
|               | Group A6                    | 0.099                             | No                     |

Due to the corrosion products generating on the surface of welded specimens increased with corrosion time increasing, the thickness of corrosion products which could inhibit the electrochemical reaction between metal and seawater increased in the process of corrosion. Thus, the corrosion rate of welded specimen decreased with corrosion time increasing. However, the average corrosion rates of corroded specimens with different level of residual stress were similar, which means that there has little influence of residual stress on the corrosion rate of overall welded structures.

3.2. Corrosion morphology

When observed, corrosion morphologies of weld joint, HAZ, and parent metal of corrode specimens were recorded respectively. The corrosion morphology evolution of weld joints processed and unprocessed by VSR are shown in Figure 1.

![Corrosion morphology evolution of weld joints](image)

Figure 1. Corrosion morphology evolution of weld joints: (a) processed by VSR; (b) unprocessed by VSR.

With corrosion time increasing, the corrosion damage of weld joints from specimens processed and unprocessed by VSR became worse simultaneously. Meanwhile, the stronger the residual stress was, the worse the corrosion damage of weld joint would be. In the initial stage of corrosion (60 d), corrosion characteristic of weld joint was pitting. Furthermore, the density of corrosion pits on the surface of weld joint increased with corrosion time increasing, and so did the depth and diameter of pits. When the corrosion time reached 180 d, corrosion pits on the surface of weld joint mutually combined, and then formed consecutive corrosion damage.

The corrosion morphology evolution of HAZ processed and unprocessed by VSR are shown in Figure 2.
After processed by VSR, the corrosion characteristic of HAZ was mainly pitting in the initial stage of corrosion. However, corrosion morphology on the surface of HAZ transformed from pitting corrosion to uniform corrosion with corrosion time increasing. The corrosion morphology on the surface of HAZ almost transformed into uniform corrosion on the corrosion time of 180d, while a few corrosion pits still existed on the surface of HAZ (Figure 2a).

The corrosion characteristic which was combined with pitting corrosion and uniform corrosion have formed in the initial stage of corrosion on the surface of HAZ unprocessed by VSR. Meanwhile, the amount and diameter of corrosion pits decreased with corrosion time increasing, and the corrosion morphology of HAZ’s surface final transformed into uniform corrosion (Figure 2b). Therefore, the transformation of corrosion morphology from pitting corrosion to uniform corrosion was accelerated with the level of residual stress increasing on the surface of HAZ, and the rate of metal loss was increased under the influence of residual stress.

The corrosion morphology evolution of parent metal processed and unprocessed by VSR are shown in Figure 3.

The corrosion morphology on the surface of parent metal was mainly consecutive corrosion groove, and the area and depth of corrosion grooves increased with corrosion time increasing. On the surface of parent metal processed by VSR, the corrosion grooves gradually generated in the process of
corrosion, while its area and depth were small. However, the corrosion grooves generated on the surface of parent metal unprocessed by VSR were obvious in the initial stage of corrosion under the influence of residual stress, and both the area and depth of corrosion groove significant increased with the corrosion time increasing.

4. Conclusion
1. In the process of corrosion, high-level of residual stress could accelerate the corrosion damage of weld joint, HAZ, and parent metal of welded structures, while had little influence on the overall corrosion rate of welded structures.

2. Under the influence of residual stress, the corrosion morphology evolution of weld joint, HAZ, and parent metal were different. The corrosion characteristics of weld joint was pitting, and then combined into consecutive corrosion damage. However, although corrosion characteristics of HAZ was pitting in the initial stage of corrosion, the corrosion characteristic of HAZ gradually transformed into uniform corrosion with the corrosion time increasing. The mainly corrosion morphology of parent metal was corrosion groove, whose area and depth increased with the corrosion time increasing.

3. Compared to the weld joint and parent metal, area with the most serious corrosion damage was HAZ. Therefore, the HAZ needs to be significant concerned while designing the corrosion failure prevention measures of the welded structures.

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