Analysis of SCC sensitive areas for X65 pipeline structure in marine environment

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Abstract. SCC sensitive areas of welded specimens in the marine environment was investigated by means of magnetic field distribution detection, residual stress measurement and corrosion morphology observation. The study found that both HAZ and parent material surfaces of welded specimens could generate high-level stress concentration areas under the action of marine environment, thereby becoming sensitive areas of SCC. The combined effect of residual stress and corrosion damage results in the formation of SCC sensitive areas. Meanwhile, SCC sensibility on HAZ and parent material surfaces are determined by residual stress level and corrosion damage degree on the structure surface, respectively. Appropriate preventive measures should be taken according to the determinant of HAZ and parent material surfaces' SCC sensibility when SCC preventive measures of X65 pipeline structure servicing in the marine environment are designed.

1. Introduction

Pipeline transportation, which has been a main transportation mode of oil and gas, was usually damaged by stress corrosion cracking (SCC) while servicing in the marine environment, reducing the security and reliability of pipeline structure.[1-3] A number of studies indicated that areas on the heat affected zone (HAZ) surface had high-incidence of SCC, and the problems about influence of residual stress on the stress corrosion behavior of welded structure has become a research emphasis in recent years, consequently.[4-6] According to Ravi Kiran,[7] the damage fracture of ductile metal is developed from nucleation, growth, and convergence. Hence, the corrosive microvoid generating on the parent metal surface could also develop into corrosion damage while servicing in the marine environment, resulting in the SCC and influence the safe use of pipeline structure which is mainly jointed by welding.

Microvoids which is in nucleation stage is difficult to be probed by instruments. However, magnetic field leakage will be produced because of stress concentration generating in the growth and convergence stages of microvoids, thus magnetic leakage detection becomes an effective method to probe earlier corrosion manage of ductile metal. Stress concentration areas on the X65 welded specimens' surfaces were measured after corrosion in the marine environment, and the forming

reasons of stress concentration areas generating on HAZ and parent metal surfaces were analyzed through residual stress measurement and corrosion morphology observation. The SCC sensitive areas of X65 pipeline structure in marine environment were studied, the results of which have great reference significance on design of SCC preventive measures of X65 pipeline structure servicing in marine environment.

2. Experimental

The chemical components of X65 used in the experiments is 0.082 C-0.009 S-0.024 P-0.21 Si-1.42 Mn, and the size of welded specimens is 350mm×150mm×10mm. The corrosion experiment with three welded specimens whose number is A1-A3 was conducted in accordance with GB/T 6384-2008 in natural seawater for 60 days. To increase the corrosion rates of welded specimens in seawater, the specimens were connected to graphite sheets. After corrosion experiment, the corrosion products were removed by acid washing，and an inhibitor was added in the acid solution to prevent reactions between corroded specimens and acid solution.

Magnetic determinator, whose type is TSC-2M-8, was used to measure the magnetic field on corrode specimens' surfaces, aiming to ensure stress concentration areas on the corrode specimens' surfaces through characteristic curve of leakage magnetic field. The compensation of magnetic determinator was opened while measuring, and the parameters of scanning step and measurement distance were 2mm and 4mm, respectively.

Residual stress distribution on corrode specimens' surfaces were measured by hole-drilling technique. In order to paste strain gauges effectively, the surfaces of corrode specimens need to be polished through high speed spindle. Hence, the additional deformation caused by polishing should be measured, using for correct the residual stress measurements of corrode specimens. The aperture and hole-depth used in the drilling process were 2mm and 1.5mm, respectively.

Corrosion morphologies of corrode specimens were observed by a type SNE 4500M scanning electron microscopy (SEM), aiming to ensure the corrosion morphologies' characteristics of stress concentration areas on the HAZ and parent metal surfaces. Thereby, the forming reasons of stress concentration areas on the corrode specimens' surfaces were achieved according to the results of residual stress measurement.

3. Results and discussion

3.1. Magnetic field measurements

Magnetic field distribution of corrode specimens' central regions were detected, aiming to ensure the stress concentration areas on the corrode specimens' surfaces. The magnetic field and magnetic field gradient are shown in figure 1. Where, Hp-1, Hp-3, Hp-5 and Hp-7 represent tangential component of leakage magnetic field (H_p^x); Hp-2, Hp-4, Hp-6 and Hp-8 represent normal component of leakage magnetic field (H_p^y).
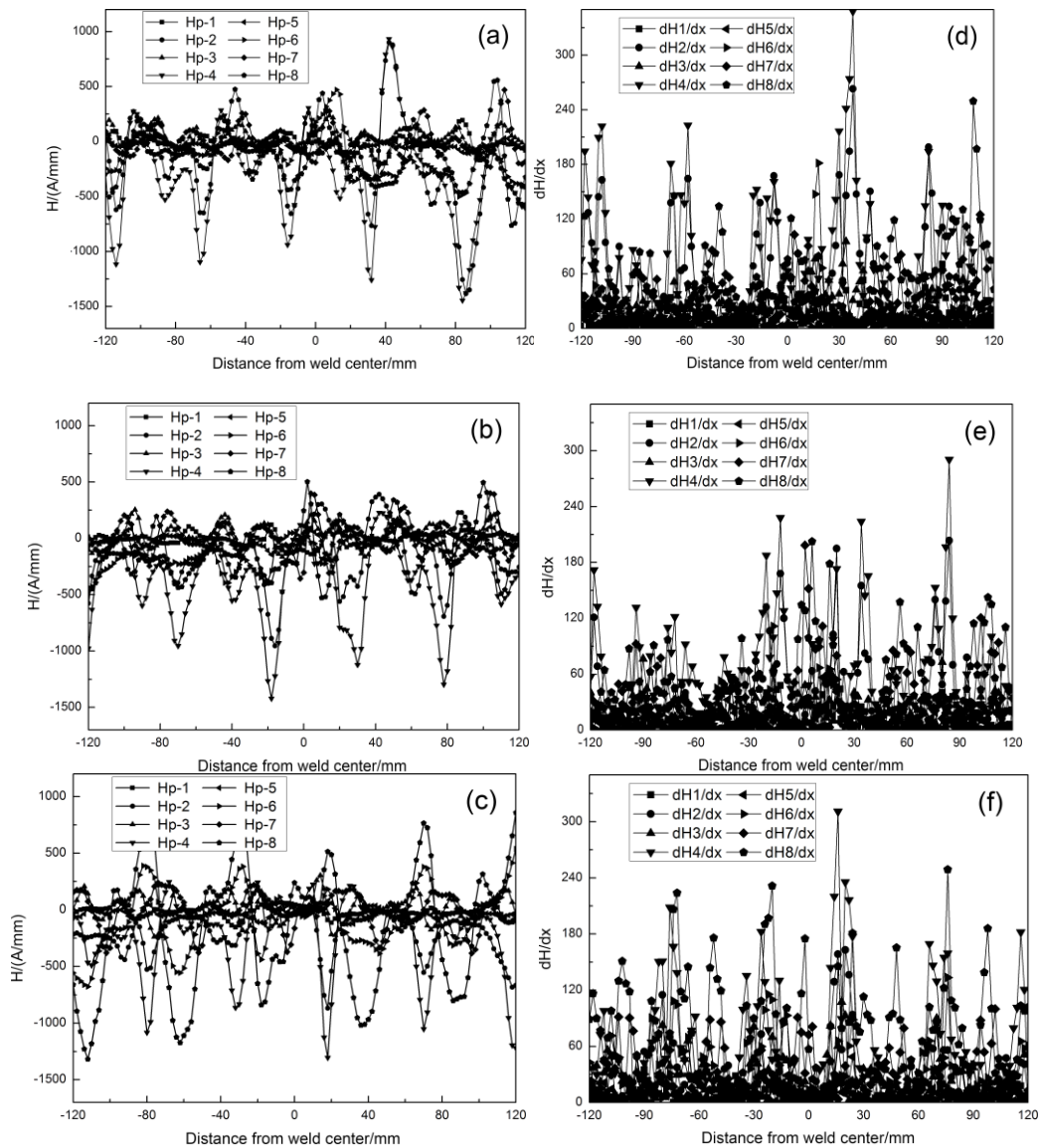
Figure 1. Magnetic field measurements: (a) magnetic field of A1, (b) magnetic field of A2, (c) magnetic field of A3, (d) magnetic field gradient of A1, (e) magnetic field gradient of A2, (f) magnetic field gradient of A3.

As shown in figure 1(a) - figure 1(c), the fluctuation exists in multiple parts of H_p^x and H_p^y on corrode specimens' surfaces, and the characteristic form of leakage magnetic field, where H_p^x reaches a maximum and H_p^y passes through zero, appears in many multiple areas. The characteristic form of leakage magnetic field distributes on both HAZ and parent metal surfaces, which is indicate that numbers of leakage magnetic points are produced on the HAZ and parent metal surfaces during corrosion process.

Magnetic field gradient of multiple leakage magnetic points on the corrode specimens' surfaces presents a higher level as shown in figure 1(d) –figure 1(f). The peaks of magnetic field gradient on A1 and A3 surfaces are located in HAZ, while the peak of magnetic field gradient on A2 surface is

located in parent metal. Therefore, high-level stress concentration areas are generated on both HAZ and parent metal surfaces of welded structure, because of the level of magnetic field gradient is proportional to the level of stress concentration.

To observe the distribution characteristics of stress concentration areas on corrode specimens' surfaces, Metal Magnetic Method System 3.0 was used to process the data of magnetic field gradient on the corrode specimens' surfaces, as shown in figure 2.
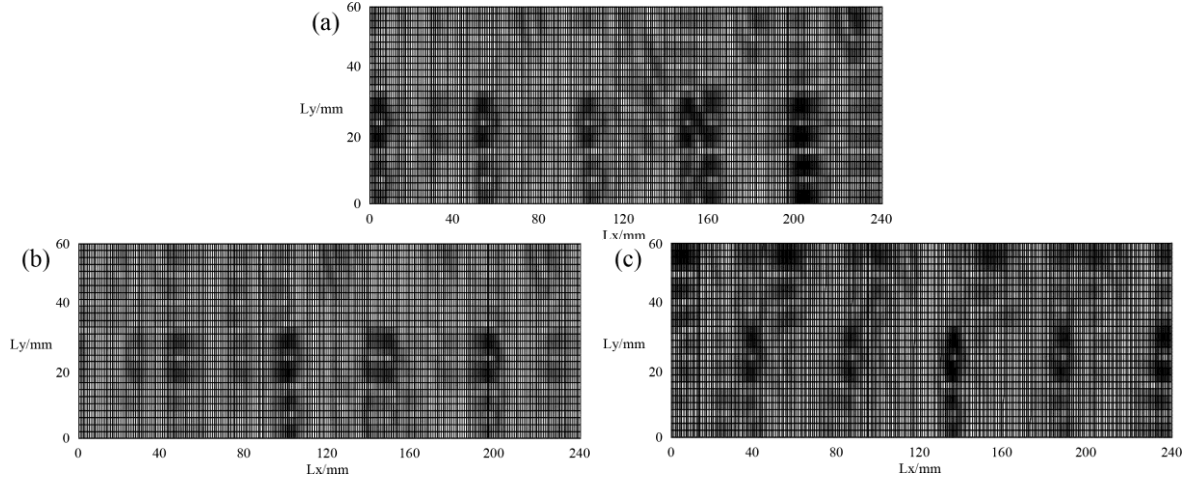

Figure 2. Magnetic field gradient distributions of corrode specimens' surfaces: (a) magnetic field gradient distribution of A1 surface, (b) magnetic field gradient distribution of A2 surface, (c) magnetic field gradient distribution of A3 surface.

In figure 2, the center of welded joint is the position Lx=120mm, and the dark areas represent the areas with higher stress concentration level, while the light areas represent the areas with lower stress concentration level.

The corrode specimens of A1-A3 are totally have high-level stress concentration areas on HAZ surfaces, as shown in figure 2. However, the position and degree of stress concentration areas on the parent metal surfaces of A1-A3 are irregular, stress concentration level on part of areas on the parent metal surfaces of A1-A3 are even larger than that on HAZ surfaces.

3.2. Residual stress measurements

The residual stress measurements of corrode specimens are shown in figure 3.
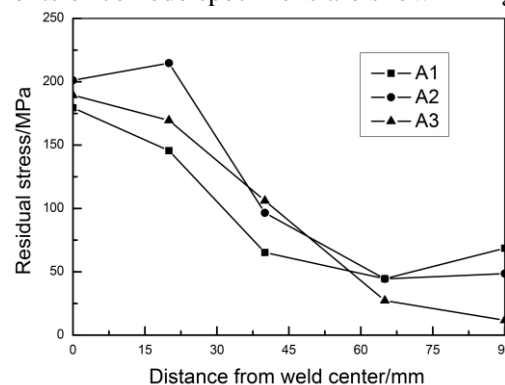

Figure 3. Residual stress measurements

As shown in figure 3, the residual stress level on the HAZ surfaces of corrode specimens is higher than other areas, and the residual stress peaks of A1-A3 are 179.5MPa, 214.7MPa and 189.4MPa,

respectively。Residual stress on the corrode specimens' surfaces decrease with increase of the distance from weld center, then remain a low level on the parent metal surface.

Hence, the generation of high-level stress concentration areas on the HAZ surface of corrode specimen are related to residual stress, while the residual stress level on the parent metal surface is much lower than that on the HAZ surface. Relying only on the residual stress on the parent metal surface is not enough to arouse the generation of high-level stress concentration areas.

3.3. Corrosion morphology measurements

A1 was selected as specimen for corrosion morphology observation to research the corrosion morphologies' characteristics on the HAZ and parent metal surfaces of corrode specimen, the corrosion morphology of A1 is shown in figure 4.
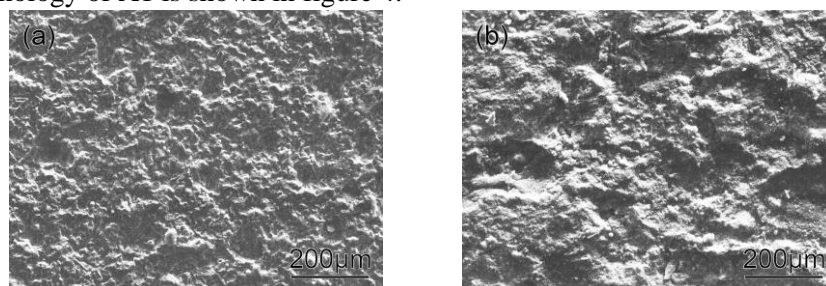

Figure 4. Surface corrosion morphologies in different areas of A1: (a) HAZ surface, (b) parent metal surface

As shown in figure 4, the corrosion morphology on HAZ surface resembles uniform corrosion, which is accompanied by a small amount of etch pits. Most of pits are in the growth stage of microvoids, whose diameters are in the range of 100μm to 150μm. Small part of pits converge together, entering into the convergence stage of microvoids. Thus, although corrosion damage on the HAZ surface have stimulative effect to the generation of stress concentration areas, the impact of corrosion manage on the generation of stress concentration areas are much lower than that of residual stress. Corrosion morphology on the parent metal surface is based on pitting and the etch pits with large diameter appears intensively in many areas, severe corrosion damage ultimately forms at the confluence of etch pits. Hence, the generation of stress concentration areas on the parent metal surface is mainly caused by corrosion damage rather than low-level residual stress.

In combination with the measurements of residual stress we can realize that the stress concentration areas generating on the HAZ and parent metal surfaces of corrode specimen is owing to the combined influence of residual stress and corrosion manage. Stress concentration areas generating on the HAZ surface are mainly caused by residual stress, while stress concentration areas generating on the parent metal surface are mainly caused by corrosion manage. Hence, appropriate preventive measures should be taken according to the determinant of HAZ and parent material surfaces' SCC sensibility when SCC preventive measures of X65 welded pipeline structure servicing under the marine environment are designed.

4. Conclusion

1. High-level stress concentration areas are produced on both HAZ and parent metal surfaces of welded structure during corrosion, increasing the SCC sensibility of welded structure. The SCC failure could occur on both HAZ and parent metal of X65 pipeline structure servicing in the marine environment under the action of corrosion.

2. The production of SCC sensitive areas is the results of combined effect of residual stress and corrosion manage. SCC sensitive areas generating in HAZ is determined by residual stress, while SCC sensitive areas generating in parent metal is determined by corrosion damage.

3. Appropriate preventive measures should be taken according to the determinant of HAZ and parent material surfaces' SCC sensibility when SCC preventive measures of X65 pipeline structure servicing in the marine environment are designed.

Acknowledgements

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