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Experimental investigation on the corrosion behavior of G20Mn5QT cast steel and butt weld with Q345D steel

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ABSTRACT

The corrosion tests of G20Mn5QT cast steel and butt weld with Q345D steel in wt 3.5% NaCl solution are conducted. The corrosion morphology of the specimens is observed by SEM. It is mainly corrosion pitting for G20Mn5QT cast steel due to the casting defect and the erosion of chloride ions. The corrosion morphology of weld zone and HAZ tends to be uniform corrosion accompanied with pitting corrosion. Welding defect and erosion of chloride ions cause pitting corrosion for weld zone and HAZ. The largest circular radius of the divided circular pits is defined as the maximum radius of the irregular pit.

1. Introduction

Cast steel joints have been widely used in the bridge and ocean engineering such as Aasta Hansteen FPSO spar (Fig. 1(a)) and Hangzhou Bay Sightseeing Tower (Fig. 1(b)) [1,2]. The application of the cast steel joints could avoid the welding at the intersection between tubular members, thus prevent the welding defects, residual stresses and thermal deformation caused by welding [3]. In addition, pitting corrosion is an important design consideration for the steel members and joints used in the bridge and ocean engineering. The appearance of pitting has an effect on the mechanical properties of the metal, and it always appears as one of the main causes of failure in the marine offshore environment even though there is extensive reliance on cathodic protection and protective coatings [4,5].

Pitting corrosion is known to be one of the major damage mechanisms affecting the integrity of many materials and structures in the bridge and ocean engineering [6]. Pit nucleation occurs at the microscopic level and some metals show preferential sites of pit nucleation. Fatigue cracks usually initiate from the corrosion pit sites. Under the interaction of cyclic load and the corrosive environment, cyclic loading facilitates the pitting process and corrosion pits, acting as geometrical discontinuities, lead to crack nucleation and propagation and then final failure [7].

In recent years, the extensive research has been conducted to investigate the corrosion behavior of the metal material in marine environments including stainless steel, carbon steel, and steel weld zone. As the detection techniques develop such as scanning electron microscope (SEM), 3D-technology, and X-Ray Diffraction (XRD), it is of the help to investigate the corrosion morphology of metals [8–11]. The metastable pitting behavior of 304 stainless steel in wt3.5% NaCl solution under different applied potentials was investigated by potentiostatic polarization and 3D video microscope. The effects of applied potential on pitting nucleation numbers, pit average lifetime, the average peak value of current transients and pit growth rate were obtained [12]. And the pitting corrosion of stainless steel has further been investigated with high-resolution in situ X-ray microtomography in 3D-technology. The growth of pits at the tip of stainless steel pins has been observed with 3D microtomography under different conditions of applied current and cell potential [13]. The effect of dichromate ions on the corrosion behavior of 316 stainless steel was investigated in 0.1 M NaCl solution by electrochemical measurements and electron microscopy. The addition of dichromate increases the resistance to pitting corrosion as the pitting corrosion does not occur in the presence of 0.05 M dichromate ions at room temperature [14,15]. Pitting corrosion occurs on carbon steel in 0.1 M $NaNO_2$ with different concentrations of NaCl. The repassivation potentials in 0.1 M $NaNO_2$ and 20 mM NaCl show the negligible difference between 20# and 45# carbon steels, which is ascribed to the absence of carbon/carbides within pits [16]. For the steel weld, the pitting tends to occur at very different rates compared with the parent metal and the heat affected zone (HAZ). The maximum pit depth in the heat affected zone for longitudinal welds on pipeline steels is about 25% greater than for the adjacent parent metal and weld zones in the period 0–55 weeks of exposure, then rapidly increasing to being about 50–100% greater for exposures up to 3.5 years [4].

The G20Mn5QT cast steel needs to be quenched and tempered after

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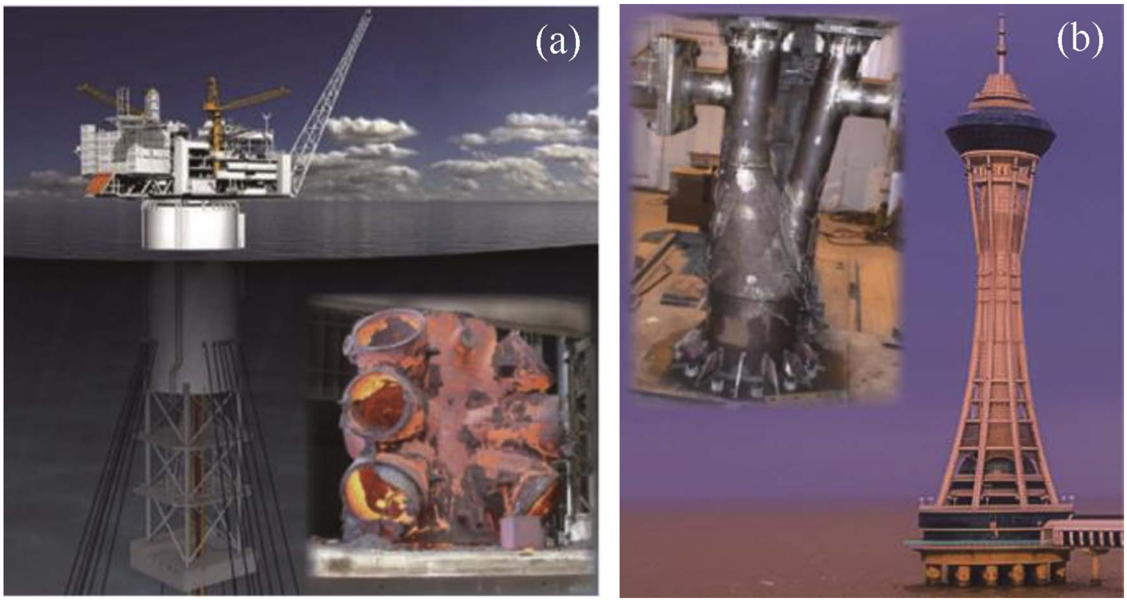

Fig. 1. Cast steel joints used in real projects. (a) Aasta Hansteen FPSO spar, and (b) Hangzhou Bay Sightseeing Tower.

casting so as to improve its mechanical properties. Thus the heat treatment process of G20Mn5QT is different with the stainless steel and carbon steel. It also has a great influence on the microstructure of cast steel, the welding performance, and the corrosion behavior in the corrosion solution [17]. The finding is that both the tempering temperature and material composition of alloy composition and carbon content have a certain influence on the corrosion behavior of steel in the corrosion solution [18–21]. Therefore, there is still an urgent need to further investigate the corrosion behavior of the cast steel and butt weld with the wide use of the cast steel joints in the marine environment.

This paper is concerned with the corrosion behavior of G20Mn5QT cast steel and butt weld with Q345D steel by the immersion technique in wt 3.5% NaCl solution. The purposes of this paper are to analyze the corrosion rate of G20Mn5QT cast steel and butt weld with Q345D steel. The corrosion mechanism of the cast steel and the butt weld with Q345D steel will be investigated by using scanning electron microscopy (SEM). Finally, the influence of the immersion time on the pitting radius of the G20Mn5QT cast steel could be analyzed.

2. Experimental

2.1. Material and solution

The tested material includes G20Mn5QT cast steel and butt weld with Q345D steel. The butt weld with V groove is fabricated by the CO_2 gas arc welding. The type of the used DC welder is PADA-AUTO KRII500. The base metal of the butt weld is the G20Mn5QT cast steel and Q345D steel. The filler metal is ER50-6 wire with diameter of 1.2 mm. The main welding parameters are listed in Table 1. The butt weld is welded by six-pass welding procedure. The graphic scheme of the welding process is schematically illustrated in Fig. 2. There are 5 weld beads to fill the weld pool and the cosmetic bead to finish the butt weld [22–24]. Table 2 presents the temperature control parameters during the welding. An additional ultrasonic inspection is performed on the welds to ensure the quality of the welding process [3]. The chemical composition of G20Mn5QT cast steel, ER50-6 wire, and Q345D steel is presented in Table 3. The test coupons of G20Mn5QT cast steel are machined to a size of 100 mm × 25 mm × 5 mm for the corrosion mechanism analysis (Fig. 3). As for the butt weld, it is the filling part of the welding. The root and finishing of the butt weld have been removed by the machining. The detail of butt weld with Q345D steel specimens

Table 1
Welding process parameters.

Welding process parameters	Values		
	1–2 weld beads	3–5 weld beads	Cosmetic bead
Wire	ER50-6	ER50-6	ER50-6
Wire diameter (mm)	1.2	1.2	1.2
Current (A)	270–280	300–320	260–380
Voltage (V)	35–38	38–40	36–38
Shielding gas	CO_2	CO_2	CO_2
Shielding gas flow rate (L/min)	40–50	40–50	40–50
Wire feed rate (m/min)[a]	9	10	9
Welding speed (cm/min)	350–450	350–450	350–450

[a] Wire feed rate depends on the welding current and voltage.

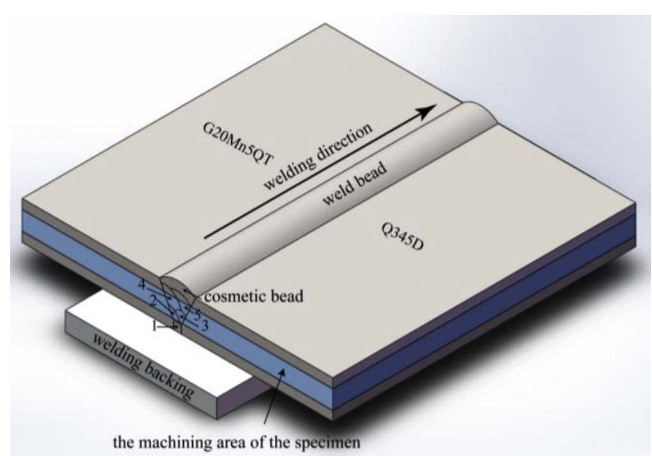

Fig. 2. The graphic scheme of the welding process.

as shown in Fig. 4. Prior to the experiments, the surface of the specimens is ground with silicon carbide (SiC) papers, progressively up to 1200 grit, rinsed with absolute ethanol and then dried in the air. After the specimens are weighed (precision 0.1 mg), then these specimens are stored in a desiccator for use [25–27].

All the corrosion experiments are carried out at the room temperature (25 °C). The corrosion medium is wt 3.5% NaCl solution