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Evaluation of the mechanical properties of the X52 high frequency electric resistance welding pipes

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ABSTRACT

The intensity assessment of the line pipe does not include the strength and the impact toughness, but also include the fatigue performance. In this paper, the tensile strength and the impact toughness of both the pipe body and the weld joint of X52 high frequency electric resistance welding (HF-ERW) pipes were measured. The amounts of fatigue for these specimens with and without surface finishing were investigated with a MTS servo-hydraulic universal testing machine at various maximum cycle stresses. The results showed that both the pipe bodies and the weld joints of the X52 HF-ERW pipes had an excellent balance of strength and impact toughness. The cyclic stress of the weld joints decreased more than the pipe bodies, and the resistance to fatigue was greatly affected by the surface defects. The effects of the surface defects on fatigue properties must be considered for the intensity assessment of line pipes.

1. Introduction

The steel pipes that are manufactured with high frequency electric resistance welding (HF-ERW) are largely used in oil and gas transportation, because they have a higher dimensional tolerance, a high production efficiency, and lower production costs than both seamless pipes and submerged arc welding pipes [1–3]. The weld seam produced with HF-ERW often has a relatively low toughness compared to other pipes. The low toughness is largely dependent on features including the microstructure and the weld defects, i.e. the cold defect and the oxide inclusion [4,5]. These could prevent the use of these high strength HF-ERW pipes in applications that require high integrity and high weld reliability. The appreciable technologies and the plasma shielded technologies have been used in quality control for assurance of the HF-ERW process. Through this, the cold defect and the oxide inclusion defects are largely avoided [6–9]. The X70 and/or the X80 grade high strength HF-ERW line pipes are acceptable for use in highly demanding and severe environments [10–12].

When the pipelines are in service, the pipeline endures the alternating stress caused by the operating pressure periodically changing because of the intermission transportation and market fluctuations. It is influenced by the alternating stress, the crack initiation, and the propagation that could occur at the original defect. This would result in fatigue failure [13–16]. The weld seam that occurs when using HF-ERW commonly has weld defects, including the cold defect and the oxide inclusion [4,5]. Therefore, the fatigue assessment of the weld joint is a key issue in the design and the safe operation of the pipeline [17,18]. Many research works focused on the fatigue crack propagation and the estimation of remaining life for the weld joint [15–18]. The previous studies mainly focused on the effects of microstructure on fatigue crack propagation and the remaining life of steel and weld joint using standard fatigue tests and/or numerical simulation [13–18]. However, fatigue processes involve crack initiation, propagation, and final fracture [19]. In the fracture process, the major part of the life is expended during crack initiation region [20]. The stress (*S*) − number of fatigue cycles (N) curve is a most effective method to evaluate fatigue life of welded components of structural stress procedure [21]. Therefore, the fatigue evaluation by the master *S-N* curve method was specified in API 579 R P/ASME FFS-1 since 2007 [22,23]. It is well known that the fatigue cracks are generated on the surface defects and the weld joints, because these defects at the stress concentration sites could induce continuous accumulation of localized irreversible slip under repeated loading. This eventually triggers fatigue crack generation [24–26]. The surface state of the pipes, including the pipe body and the weld joint, becomes an important factor that affects the entire fatigue life. The effects of the surface state on the fatigue life must be considered for the

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Table 1
Chemical composition of the API X52 pipeline steel (wt.%).

C	Si	Mn	P	S	Cr	Al	Ti	Nb
0.06	0.21	1.06	0.012	0.002	0.15	0.028	0.01	0.03

integrity of the HF-ERW pipe evaluation.

In this study, the microstructure, the strength and the impact toughness of X52 HF-ERW pipes, including the pipe body and the weld joint, were evaluated. The fatigue life of the pipe body and the weld joint with and without surface finishing were measured under various maximum cycle stress conditions. The effects of the surface defects on the fatigue crack initiation were taken into consideration. This study will provide beneficial experimental data for the safe design of pipelines, and the improved quality of the HF-ERW pipe.

2. Experimental procedures

API X52 grade HF-ERW pipe manufactured for Oman project were used to study the microstructure, the mechanical properties, and the fatigue life of the pipe body and the weld joint. The chemical composition of the X52 steel is shown in Table 1, and the mechanical properties of API Specification 5 L PSL2 45# for Oman project are listed in Table 2. The API X52 HF-ERW pipe was manufactured from hot-rolled API X52 microalloyed steel strips with 8.2 mm thickness by forming, HF-ERW, deburring, on-line post-weld heat treatment and so on to fabricate pipes with 219 mm external diameter. The normalizing was performed on weld joint as on-line post-weld heat treatment, The weld joint was heated to 920 °C by on-line high-frequency induction heating, and then air cooled to 400 °C, subsequently, water cooled to room temperature.

The specimens of the pipe body and the weld joint were cut from the weld joint and prepared from 180° along the circumference of the pipe in accordance with the API specifications for fabricating pipelines as schematically shown in Fig. 1. The method and the size of the specimens of the pipe body and the weld joint sampled from the pipe are shown in Fig. 1(b). Two typical strip specimens of the pipe body and the welded joint were used. The first is full-thickness strip specimens: the as-rolled surface of strip specimens was not subjected to machining (without surface finish) (Fig. 1(b)). The aim was to provide results that would reflect the actual fatigue life of the pipe. The second is the smooth milling specimens: the as-rolled surface of the strip specimens were milled (with surface finish). The aim was to provide results that would demonstrate the effect of the surface defects on the fatigue life of the HF-ERW pipes.

The fatigue life tests were performed with a MTS servo-hydraulic universal testing machine. A stress ratio ($R = \sigma_{\min}/\sigma_{\max}$) of 0.1, a sinusoidal wave form, and a 10 Hz frequency were used for all of the tests. The maximum stress was applied as a controlled load, at each of the seven stress levels. Each fatigue specimen was examined until it fractured. The total fatigue cycles were calculated and served as the fatigue life measurements.

Microhardness tests were performed on the polished specimens, across the weld seam, with a FMARS-9000 Vickers hardness tester (load = 100 gf). The analysis of the microstructures was performed with an optical microscopy (OM) and an S-3400 N scanning electron microscopy (SEM).

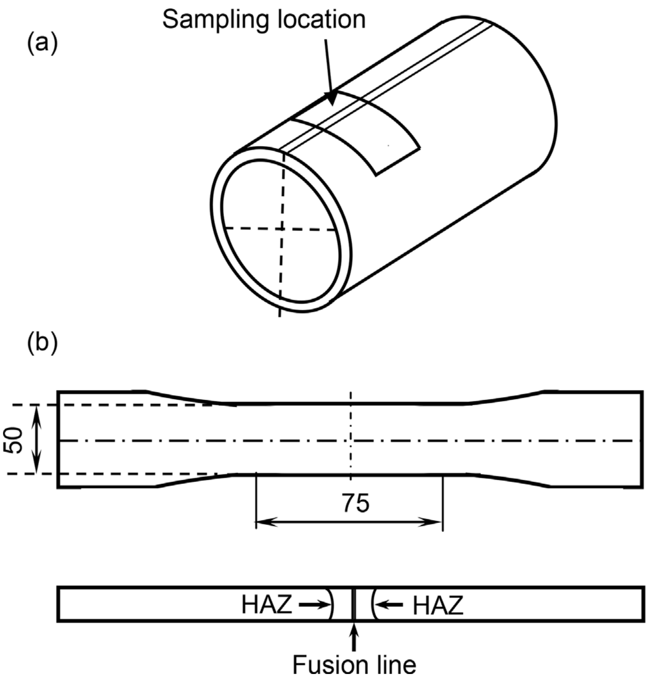

Fig. 1. (a) Schematic illustrations for locations of cut and preparation of the test specimens; (b) The critical dimensions of the fatigue test specimens (all dimensions are in mm).

3. Results

3.1. Mechanical properties of the X52 HF-ERW pipe

The mechanical properties of total 20 batches of the X52 steel strips and HF-ERW pipes are shown in Table 2. The pipes had better mechanical properties, which are higher than the values specified by API 5 L (Table 2). However, comparing the steel strips with the pipes, some changes can be found. The yield and the tensile strength increased about 15 MPa and 5 MPa. The elongation decreased about 4% and the impact energy decreased about 10 J. For weld joint, the impact energy of the weld seams decreased about 30 J more than the pipe bodies, and the impact energy of the heat affected zone (HAZ) is the same to the pipe bodies.

The typical tensile curves of the X52 steel strips, the pipe body, and the weld seam are shown in Fig. 2. The tensile curve of the steel strips appeared to be a common characteristic of low-carbon steel, which had typical yield point elongation. While, the yield point elongations was not observed in the tensile curves of the pipe body and the weld seam. The yield strength increased, which was attributed to deformation of the pipe forming and being flattened into the pipe sample [27]. The tensile strength changed a little and the ductility decreased. The uniform elongation of the weld joint was lower than the pipe body. The results indicated that the fatigue specimens should be sampled from the

Table 2
The mechanical properties of the API X52 HF-ERW pipes.

	Yield strength/MPa	Tensile strength/MPa	Elongation/%	Impact energy(Akv) (0 °C)/J
Specification	360–530	460–760	≥25	Single ≥ 14; Average ≥ 18
Steel strip	479 ± 16	535 ± 12	42 ± 2	220 ± 21
Pipe body	494 ± 14	540 ± 11	38 ± 3	212 ± 17
Weld joint	–	542 ± 16	–	178 ± 28 (WF); 210 ± 21 (HAZ)

Note: the size of Charpy impact specimen is 10 × 6.7 × 55 mm, 2 V mm.