Journal of Materials Processing Technology 164–165 (2005) 1007–1013

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Hydrogen assisted cracking of high-strength weldable steels in sea-water

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Abstract

Hydrogen degradation of high-strength steels and their welded joints has been evaluated under various load modes in sea-water. Slow-strain rate tensile test (SSRT), and low-cycle fatigue test were carried out in sea-water under cathodic polarisation.

Two steel grades with minimum yield strength of 690 MPa, and theirs submerged arc welded (SAW) and shielded metal arc welded (SMAW) joints were examined.

For SSRT the applied strain rate was 10^{-6} s^{-1}. Relative values of: fracture energy, elongation, reduction in area and tensile strength were chosen as measures of hydrogen degradation.

For fatigue test uniaxial tension loading under strain control ($R = 0$, $\Delta\varepsilon = 0.2$–8%) was carried out at frequency 0.1 s^{-1}. Reduction of time to failure was a measure of hydrogen degradation. Fracture modes were investigated with the use of a scanning electron microscope (SEM).

Keywords: Hydrogen embrittlement; Stress corrosion cracking; Corrosion fatigue; High-strength low-alloy steel; Sea-water

1. Introduction

High-strength low-alloy (HSLA) steels are used for advanced marine constructions like offshore, tankers, and navy ships. Among theme, extra high-strength steels have minimum yield strength ranging from 420 to 690 MPa, good toughness, and weldability. Extra high strength steels are produced as: quenched and tempered, direct quenched and tempered (the kind of thermo mechanical controlled process, TMCP), or precipitation hardened with copper [3]. Especially, quenched and tempered steels are thought to be sensitive to hydrogen degradation [5].

Significant limitation of use of extra high-strength steels could be their hydrogen degradation. Hydrogen degradation may occur during:

- fabrication of a construction in a form of cold cracking of welds,
- service of a construction in corrosive environment in a form of hydrogen embrittlement (HE), hydrogen induced cracking (HIC), and hydrogen enhanced stress corrosion cracking (SCC) or corrosion fatigue (CF) [2,6,7,9].

Corrosion of marine constructions is prevented by coatings and cathodic protection. The later may be harmful for steels resulting in their hydrogen embrittlement. Steel could be charged with hydrogen in the vicinity of polarisation anode, i.e. over-protection, or by presence of some sulfate-reducing bacteria in sea-water. Additionally, welded joints contain some amount of hydrogen introduced into a material during welding. This could increase a risk of hydrogen degradation during service [1,8].

The aim of the paper is to evaluate the degree of hydrogen degradation for extra high-strength steels and their welded joints.

2. Experimental and results

Quenched and tempered plates 12 mm in thickness made of 17HMBVA and 14HNMBCu steel grades, with minimum yield strength 690 MPa were used. The chemical compositions of the tested steels are given in Table 1.

Submerged arc welded (SAW) and shielded metal arc welded (SMAW) joints were prepared for each steel grade. Mechanical properties obtained from a tensile test performed according to PN-EN 10002-1-1998 are presented in Table 2.

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doi:10.1016/j.jmatprotec.2005.02.083

Table 1
Chemical composition of steel plates (control analyse)

Steel grade	Chemical composition (wt.%)												
	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Ti	V	Al	B
17HMBVA	0.15	0.28	0.77	0.006	0.011	0.42	0.05	0.16	0.17	0.013	0.06	0.03	0.002
14HNMBCu	0.13	0.21	0.83	0.001	0.005	0.43	0.74	0.40	0.25	0.004	0.05	0.02	0.002

Table 2
Mechanical properties (transverse direction) of steel plates and their welded joints

Steel grade	Samples	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction in area (%)
17HMBVA	Base metal	811	863	10.4	63.0
	SAW	470	567	7.9	59.6
	SMAW	556	639	8.1	67.9
14HNMBCu	Base metal	908	935	8.7	47.4
	SAW	601	631	7.2	55.5
	SMAW	599	687	6.6	61.9

Hardness distribution in the welded joints was measured on a cross-section with the Vickers method using 98.07 N load according to PN-EN 1043-1: 2000 (Fig. 1).

Microstructures of the steel plates and welded joints were examined with the use of the optical microscope LEICA MEF4M according to PN-EN 1321: 2000. Microstructure of the steels composed of low carbon tempered lath martensite. Microstructure of the welded joint was typical for extra high-strength low-alloy steel. Weld metal microstructure composed of acicular ferrite and bainite. Microstructure of regions of HAZ (coarse grained region, fine grained region, and intercritical region) consisted low carbon lath martensite with various prior austenite grains size, respectively.

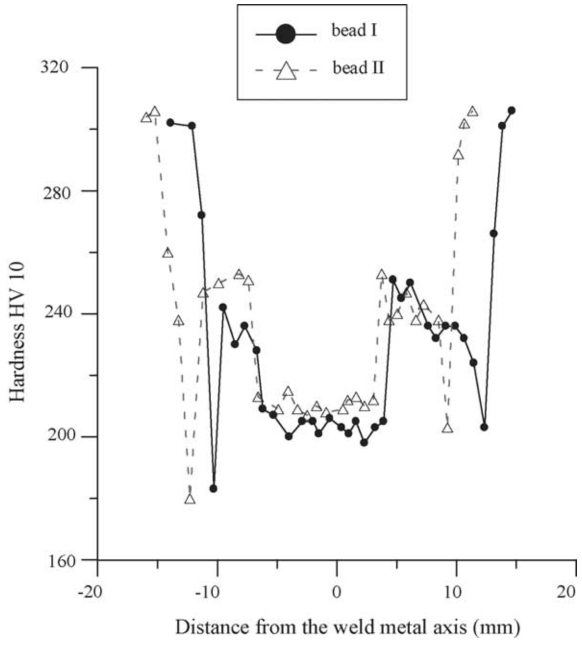

Fig. 1. Hardness (HV10) distribution in the SAW welded joint of 17HMBVA steel.

In order to estimate the degree of hydrogen degradation of tested steels and their welded joints, slow strain rate test (SSRT) along with PN-EN ISO 7539-7 was conducted on round smooth specimens 4 mm in diameter made according to PN-EN ISO 7539-4. The gauge length was 50 mm. Welded joints were placed in the centre of specimens. Specimens were cut along the transverse direction. Tests were performed at ambient temperature either in dry air or in standard artificial sea-water grade A, prepared consistent with PN-66/C-06502. The applied strain rate was $10^{-6}\,s^{-1}$. Tests in sea-water were conducted under free potential and cathodic polarisation with constant current densities chosen from the polarisation curves obtained in artificial sea-water for base metals with the potentiostatic method. The following cathodic currents were applied: 0, 0.1, 1, 10, 20 and 50 mA/cm^2. During tests stress-strain curves were recorded on a personal computer. Three samples were used for tests in air and two samples for each parameter in sea-water.

Fracture energy, time to failure, elongation, reduction in area, and tensile strength were chosen as measures of hydrogen degradation (Fig. 2). Then, relative parameters determined as the ratio of the appropriate value measured in air to that measured in artificial sea-water were calculated (Tables 3 and 4) and presented as bar charts (Fig. 3).

Low-cycle corrosion fatigue tests were performed on cylindrical smooth specimens 4 mm in diameter with 50 mm gauge length. Sinusoidal wave form uniaxial tension loading under strain control ($R = 0$, positive strain amplitude $\Delta\varepsilon = 0.2\%$, 0.3%, 0.4%, 0.5%, 0.8%, 1%, 2%, 4% and 8%) was carried out at frequency $0.1\,s^{-1}$. Tests were performed at room temperature either in ambient air or standard artificial sea-water under cathodic polarisation. Applied current density of 10 mA/cm^2, giving the highest degradation of plasticity was chosen from previously performed SSRT research. Results of fatigue test for 17HMBVA steel is presented in Fig. 4.

Fracture surfaces of SSRT and CF samples were investigated with the use of the scanning electron microscope