Achievements in
Mechanical and
Materials
Engineering

COMMENT Worldwide Congress on Materials and Manufacturing Engineering and Technology
16th - 19th May 2005
Gliwice-Wisła, Poland

COMMITTEE OF MATERIALS SCIENCE OF THE POLISH ACADEMY OF SCIENCES, KATOWICE, POLAND
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, GLIWICE, POLAND
ASSOCIATION OF THE ALUMNI OF THE SILESIAN UNIVERSITY OF TECHNOLOGY, MATERIALS ENGINEERING CIRCLE, GLIWICE, POLAND
13th INTERNATIONAL SCIENTIFIC CONFERENCE
ON ACHIEVEMENTS IN MECHANICAL AND MATERIALS ENGINEERING

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

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Abstract: Hydrogen degradation of high-strength steel 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.

17HMBVA steel grade 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 TMCP - Thermo Mechanical Controlled Process), or precipitation hardened with copper [2]. Especially, quenched and tempered steels are thought to be sensitive to hydrogen degradation. Significant limitation of use of extra high strength steels could be their hydrogen degradation [1, 3-5].

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

2. EXPERIMENTAL AND RESULTS

Quenched and tempered plate 12 mm in thickness made of 17HMBVA steel grade, with minimum yield strength 690 MPa was used. The chemical compositions of the tested steel are given in Table 1.

Table 1.
Chemical composition of 17HMBVA steel plate (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

Submerged arc welded (SAW) and shielded metal arc welded (SMAW) joints were prepared.

In order to estimate the degree of hydrogen degradation of tested steel and their welded joints, slow strain rate test (SSRT) according to PN-EN ISO 7539-7 was conducted on round smooth specimens 4 mm in diameter made along with PN-EN ISO 7539-4. The gage 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 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. Then, relative parameters determined as the ratio of the appropriate value measured in air to that measured in artificial sea-water were calculated (Table 2).

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 Figure 1.

3. DISCUSSION

The tested steels and theirs welded joint decrease their mechanical properties at slow strain rate test in artificial sea-water under cathodic polarisation. A decrease is observed for fracture energy, time to failure, elongation, and reduction in area, while tensile strength is at constant level, so it is evidence of hydrogen degradation.

Fractures were observed mainly in weld metal or in a fusion line. Thus, the importance of microstructure in HE and SCC should be taken into account. Weld metals had lower strength and hardness compared to base metal and HAZ, so plastic deformation started there increasing hydrogen absorption. Higher degradation was found for welded joints than for base metal, and generally SMAW were more susceptible to hydrogen degradation than SAW.

Table 2.
Relative values of hydrogen degradation parameters for 17HMBVA steel and its welded joints

Cathodic current density		Time to fracture	Fracture energy	Elongation	Reduction in area	Tensile strength
mA/cm^2		%	%	%	%	%
0	BM	84.6	89.3	90.4	96.7	100.6
	SAW	89.6	90.1	87.3	82.6	100.7
	SMAW	79.3	77.1	77.8	94.1	101.9
0.1	BM	70.0	68.5	69.2	57.0	101.2
	SAW	59.4	55.8	54.4	31.7	101.6
	SMAW	60.5	61.1	63.0	52.9	101.3
1	BM	73.8	73.0	75.0	39.5	100.7
	SAW	57.2	51.5	51.9	28.0	101.9
	SMAW	54.1	50.6	53.1	44.0	101.3
10	BM	71.2	55.1	58.7	39.5	101.3
	SAW	55.3	48.7	46.8	24.2	102.5
	SMAW	43.1	36.9	42.0	34.5	96.4
20	BM	64.4	65.1	69.2	41.4	98.8
	SAW	60.0	52.5	50.6	20.3	101.1
	SMAW	31.4	22.5	29.6	24.6	93.0
50	BM	70.3	58.7	64.4	34.8	99.8
	SAW	57.8	42.9	43.0	12.4	104.8
	SMAW	47.4	41.3	44.4	27.8	102.0

BM - base metal

Observed decrease of relative values of fracture energy, time to failure, elongation, and reduction in area with the increase of current density exhibits a certain minimum. Further increase of current density does not cause higher degradation. The loss of plasticity was as high as 70-90% for welded joints. The reduction of ductility by hydrogen was accompanied by a change in fracture mode. For samples tested in air crack growth occurred in a ductile mode with microvoid coalescence and quasi-cleavage fracture. For samples tested in sea-water transgranular brittle mode with quasi-cleavage and cleavage fracture was observed. At higher cathodic current densities the presence of hydrogen induced microcracks appeared.

Significant reduction of a fatigue life time (20-80%) due to hydrogen absorption was also observed. Reduction of a relative fatigue life time increased with increase of strain amplitude (Figure 1). Fatigue fracture surfaces exhibited aligned bands of facets. Striations were not observed on the facets. Regions of serrated, transgranular tearing were also presented.

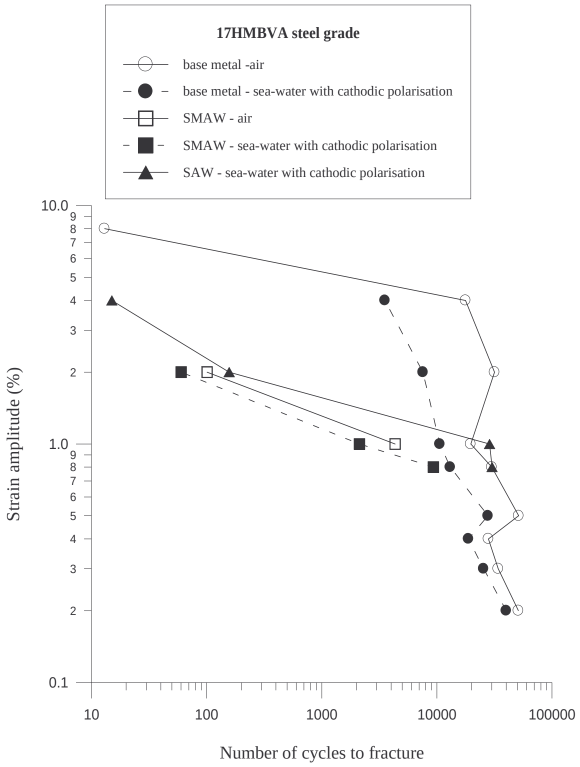

Figure 1. Number of cycles to fracture vs. strain amplitude for 17HMBVA steel

4. CONCLUSIONS

- Application of the extra high-strength steels for marine constructions under hydrogen entry could be associated with a risk of brittle cracking.
- Especially, welded joints are susceptible to hydrogen-enhanced SCC, the loss of plasticity was as high as 70-90% for welded joints.
- Significant reduction of a fatigue life time (20-80%) due to hydrogen absorption was also observed for extra high-strength steel.

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