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GENERAL AND GALVANIC CORROSION OF STEEL WELDMENTS IN SYNTHETIC SEA WATER

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The general and galvanic corrosion behaviour of steel welds, welded using E7018 welding electrode were studied in 3.5% NaCl solution and synthetic sea water. Weld metal corrodes higher than the parent metals ASTM A36 steel and API 2H steel. Post weld heat treatment at 873 K improves the corrosion resistance. Addition of copper and nickel to E7018 welding electrode makes the weld metal more corrosion resistant. The galvanic corrosion measurements between the parent metals and the weld with and without the addition of copper and nickel were made and the results are discussed.

Keywords: Galvanic corrosion, steel weldments and synthetic sea water

INTRODUCTION

In offshore platforms, failures occur due to corrosion of welds. Structural members are joined by welding. Welding causes inhomogenities. Residual stresses are introduced in the structures during welding. Weld metal may not have the same composition, hardness, strength, microstructure, surface conditions as the parent metal. Hence, the corrosion behaviour of the weld metal is different from that of the parent metals. There have been reports of corrosion rates up to 10 mm/y in steel welds in sea water [1]. Systematic investigations were carried out to study the corrosion behaviour of steel weldments in sea water. The general corrosion behaviour of the parent metals and the weld in synthetic sea water and 3.5% NaCl solution were investigated using electrochemical technique. The galvanic corrosion between the weld and the parent metals were studied using zero resistance ammeter. If unalloyed welding electrodes are used the weld zone corrosion occurs [3]. Alloying elements are added to improve the corrosion resistance of the weld [7], and its corrosion resistance was evaluated in synthetic sea water and 3.5% NaCl solution through galvanic current measurements.

EXPERIMENTAL

Welding

ASTM A36 and API 2H steels of 300 mm x 150 mm x 25 mm size were joined together by Manual Metal Arc Welding (MMAW) using E7018 supratherme welding electrodes, diameter ranging from 3.15 mm to 4 mm at the WRI, Trichy as per AWS D.1.1 structural welding code. The welding parameters and conditions are shown in the Tables I and II respectively. The chemical composition of the parent metals (ASTM A36 and API 2H) and the weld are given in Table III.

The stress relief heat treatment for the weld metal specimens were carried out in the furnace at 873 K for one hour after which the specimens were cooled in the furnace.

E7018 electrode metal was cut into small pieces, and 1.1% copper and 0.72% nickel were added to the electrode metal. The melting was done in a silica tube under vacuum.

Only specimens of 10 mm x 10 mm x 10 mm were prepared and used for corrosion studies. Only 1 cm^2 area was exposed to the solution and the remaining area was masked with araldite. This area was abraded with 1/0, 2/0, 3/0 and 4/0 grade emergy papers, washed in distilled water and degreased with trichloroethylene before corrosion studies. 3.5% NaCl and synthetic sea water were the test solutions.

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TABLE I: Welding parameters
Radiographic Examination: 100 % X-ray
Electrodes: backing at 573 K for 2 hrs then 373 K holding during welding

Pass No	Electrode Size	Amp.	Volts	Travel speed mm/min	Joint Detail
1	3.15	110-115	24-25	70-80	
2	3.15	125-130	24-25	45-50	
3	4.00	155-165	24-25	45-55	
4	4.00	155-165	24-25	60-80	
5	4.00	155-165	24-25	60-80	
6	4.00	155-165	24-25	60-80	
7	4.00	155-165	24-25	60-75	
	Back	gauge	and ground		
8	4.00	170-185	24-25	50-70	
9	4.00	170-185	24-25	50-70	

Polarisation studies

Polarisation measurements were made on the weld, ASTM A36 steel, API 2H steel and post weld heat treated metal. The potential scanned was over 200 mV on either side of the corrosion potential at a scan rate of 1.0 mV/sec using an EG&G PAR Model 173 potentiostat coupled with Hewlett-Packard 70048 X-Y recorder. The potentials were measured against SCE. All the electrochemical measurements were made at room temperature. The corrosion currents, i_{corr} were determined by extrapolating the Tafel region to the corrosion potential, E_{corr}.

Galvanic Corrosion Measurements

The galvanic current measurements were made on the following couples in 3.5% NaCl and synthetic sea water.

TABLE II: Welding conditions

Material	ASTM A36
Welding Process	SMAW
Manual or machine	Manual
Position of welding	IG
Filler metal	E7018-Supratherme
Single or Multipass	Multipass
Welding current	D.C. Electrove +Ve
Preheat temperature	Ambient (294 K min)
Interpass temperature	533 K max
Interpass cleaning	Chipping and wire brushing
Root treatment	Back gouging and grinding
Pass heat-treatment	Nil

TABLE III: Chemical composition of the weld metal and the parent metals

	C	Mn	S	P	Si	Cu	Ni	Cr	Al
A36 Steel	0.15	1.17	0.018	0.013	0.11	0.042	—	0.014	0.078
API 2H Steel	0.23	1.17	0.010	0.011	0.18	0.110	0.230	0.016	0.043
Weld Metal	0.07	1.03	0.021	0.010	0.33	0.046	0.068	0.030	0.035

1. Weld vs ASTM A36 steel (parent metal)
2. Weld vs API 2H steel (parent metal)
3. PWHT vs ASTM A36 steel
4. PWHT vs API 2H steel
5. Weld with Cu & Ni vs ASTM A36
6. Weld with Cu & Ni vs API 2H

An aera ratio of 1:1 was used for both the couples. The couples were electrically joined before exposure and then immersed in the test electrolyte. The galvanic current measurements were made for a period of 48 hours using Z -- R -- A.

RESULTS AND DISCUSSION

General Corrosion

The corrosion currents, i_{corr} determined by extrapolating the Tafel regions for the weldment to the corrosion potential are given in Table IV. It can be seen from the Table that the weld metal corrodes about two times higher than both the parent metals in 3.5% NaCl solution and synthetic sea water. The increase in the corrosion rates for the weld metal is due to the presence of residual stresses and also the presence of higher silicon content than the parent metals. Weld metal with high silicon (> 0.25%) has less corrosion resistance than low silicon (< 0.15%) weld metal [1]. High silicon in the weld

TABLE IV: Polarisation data

Metal	Corrosion current in 3.5% NaCl A/cm^2	Corrosion current in synthetic sea water A/cm^2
API 2H Steel	8.4	8.0
ASTM A36 Steel	11.0	9.0
Weld Metal	15.0	13.0
PWHT	7.0	6.0

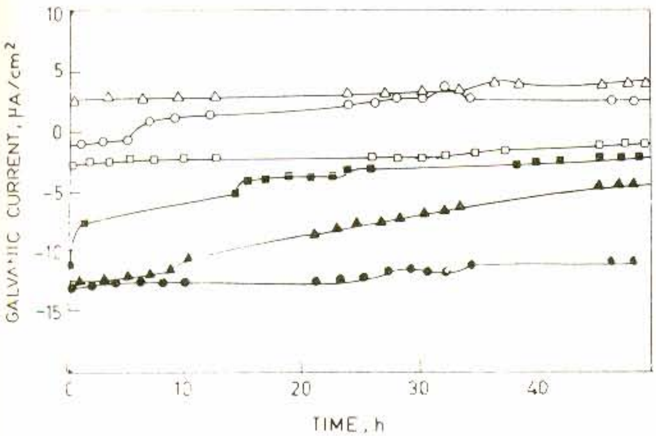

Fig. 1: Galvanic corrosion current for the various couples in 3.5% NaCl

ASTM A36 steel vs PWHT weld
API 2H steel vs Weld
ASTM A36 steel vs weld
API 2H steel vs PWHT weld
API 2H steel vs weld with addition of copper and nickel
ASTM A36 steel vs weld with addition of copper and nickel

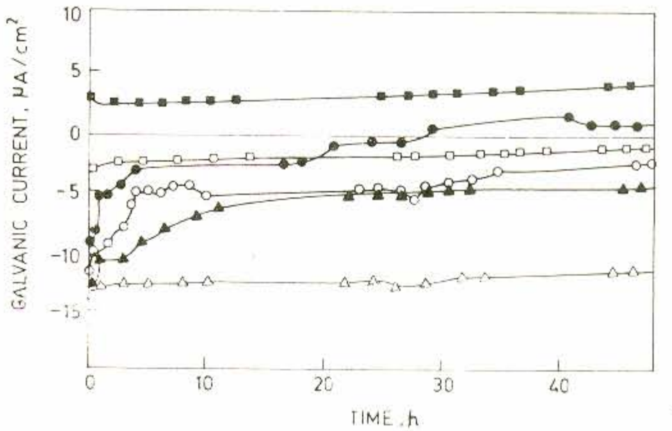

Fig. 2: Galvanic corrosion current for the various couples in synthetic sea water

API 2H steel vs weld with Cu and Ni
ASTM A36 steel vs with Cu and Ni
API 2H steel vs PWHT weld
ASTM A36 steel vs PWHT weld
API 2H steel vs weld
ASTM A36 steel vs weld

metal makes the weld metal as less noble and leads to higher corrosion rates.

PWHT at 873 K improves the corrosion resistance. The corrosion rate for the weld metal is 15 A/cm^2 in 3.5% NaCl solution and 13 A/cm^2 in synthetic sea water while the corrosion rate for PWHT metal is 7 A/cm^2 in 3.5% NaCl solution and 6 A/cm^2 in synthetic sea water. Thus, the PWHT improves the corrosion resistance about 2 times than the weld metal. After the PWHT the corrosion rate is almost equivalent to the parent metals.

Galvanic Corrosion

The results of the galvanic corrosion currents measured for the weldments, PWHT and the weld with 1.1% Cu and 0.72% Ni in 3.5% NaCl solution and synthetic sea water after 48 hours of the exposure are shown in Figs. 1 and 2 and Table V. The weld is always anodic with respect to both the parent metals. At the end of 48 hours, the galvanic current density was the highest for the weld-API 2H couple, -11.8 μA/cm^2 and lowest for the weld-ASTM A36 couple, -4.8 μA/cm^2 in synthetic sea water. Thus, the galvanic current density for the weld-API 2H steel is about 3 times higher than the weld-ASTM A36 couple. The higher galvanic currents measurement in weld-API 2H couple may be due to the presence of residual stresses introduced during welding and also to the difference in the composition of the weld metal and API 2H steel (Table III). The weld metal contains higher silicon content (0.35%) than API 2H steel (0.18%) with silicon content greater than 0.25% behave as most less noble metals [1-3]. However, API 2H steel contains more copper and nickel than weld metal. Hence, the weld-API 2H couple has higher galvanic current density than the weld-ASTM A36 couple. Weld metal may not have the same composition, microstructure, surface conditions as the parent metal. Weld metal corrosion in ships was attributed to galvanic corrosion between weld metal and parent metal [8].

TABLE V: Galvanic current measurement after 48 hours in 3. 5% NaCl and synthetic sea water

Galvanic couple	Galvanic currents A/cm^2		Remarks
	3.5% NaCl	SSW	
Weld vs ASTM A36 steel	-4.2	-4.8	Weld is anodic
Weld vs API 2H steel	-10.2	-11.8	Weld is anodic
PWHT vs ASTM A36 steel	+2.9	+0.8	Weld is cathodic
PWHT vs API 2H steel	-1.6	-2.3	Weld is anodic
Welding electrode with Cu and Ni vs ASTM A36 steel	+4.0	+3.6	Weld is cathodic
Welding electrode vs API 2H steel with Cu and Ni	-1.0	-1.4	Weld is anodic

PWHT improves the galvanic corrosion resistance of the weld vs ASTM A36 and weld vs API 2H steel couples. It is to be noted here that in PWHT/ASTM A36 couple, the weld becomes slightly cathodic. In general, it would be preferable for the weld metal to be somewhat cathodic because of its relatively small area as compared with the parent metal [4,5].

Addition of 1.1% Cu and 0.72% Ni to the E7018 welding electrode has the highest galvanic corrosion resistance (Table V). In welding electrode with Cu and Ni vs ASTM A36 couple, weld as cathodic. Cu stabilizes the corrosion product, thereby reducing the corrosion rate [6]. The addition of Cu to mild steel decreases the corrosion tendency since Cu segregates to the matrix as well as the inclusions [7]. The weld corrosion can be eliminated using a suitably balanced electrode material. Matching composition electrodes are preferred for the highest corrosion resistance. If unalloyed weld electrodes, the weld itself is corroded preferentially [3]. Alloying elements are added to the coated electrode as a means of modifying or controlling the chemistry of the weld metal. Welding electrodes with increased Cu or Ni were more resistant to corrosion [1]. Electrodes with about 0.5% Cu and 0.5% Ni have been employed to overcome the preferential weld metal attack at shielded metal arc welds in carbon steel piping [9].

Corrosion of the weld metal can occur due to improper choice of welding electrodes. Premature failure of a A53 steel pipeline by weld corrosion on the process stream was observed [2]. This was due to the galvanic corrosion between E6010 weld metal and A53 steel pipe.

CONCLUSIONS

General corrosion studies in synthetic sea water and 3.5% NaCl show that the weld metal corrodes higher than the parent metals. PWHT improves the resistance of weld zone corrosion.

Galvanic current measurements made on the weldments in synthetic sea water and 3.5% NaCl reveal that the unalloyed weld is always anodic to both parent metals. However, welding electrodes with 1.1% Cu and 0.72% Ni alloying elements makes the weld slightly cathodic.

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