JMEPEG (2010) 19:257–263
DOI: 10.1007/s11665-009-9444-4

©ASM International
1059-9495/$19.00

Investigations on the Suitability of Coated Steel Piping System for High Pressure Seawater Reverse Osmosis Application

Mohammad Mobin

(Submitted October 13, 2008)

This study deals with the investigations concerning with the suitability of coated steel piping system as an economically viable alternative to costly stainless steel piping for high pressure seawater reverse osmosis (SWRO) application. The piping system selected for investigation is a carbon steel piping coated internally and externally with thermoplastic coating (coating powder Plascoat PPA 571). The performance of thermoplastic coating was investigated by conducting SWRO pilot plant test, salt spray test, mechanical tests and testing of the coating under crevices (both in pilot plant and laboratory), and for leachable organics and inorganics (both in laboratory and pilot plant test). The testing of coating in the pilot plant resulted in the formation of some blisters on the internal surface of the pipes. The blisters were broken causing the corrosion of underneath steel. The coating showed a poor resistance to salt fog test. In general, the coating performed satisfactorily under the crevices but showed blistering on either side of the test panels. The adhesive strength of the coating was found to be poor; however, it showed good flexibility. The results of chemical analysis did not show the leaching of organic or inorganic pollutants from the coating.

Keywords adhesion test, crevice corrosion test, pilot plant, salt spray test, seawater reverse osmosis, thermoplastic coating

1. Introduction

The Seawater reverse osmosis (SWRO) plant, a relatively new technology developed in 1970s, contributes in production of major amount of drinkable water from seawater. The SWRO process requires careful filtration of the feed water to avoid blockage of the membranes. The materials used down stream of the fine filter (micron cartridge filter) should have good corrosion resistance not only to ensure their integrity, but also to avoid contaminating the filtered feed with corrosion products. In SWRO high pressure applications, the austenitic stainless steels are the main constructional materials and constitute substantial cost of the capital cost of the installation. In early SWRO plants commissioned in late 1970s to late 1980s, the high pressure parts were made of stainless steel AISI grade 316L and 317L. But these alloys were subjected to crevice and pitting corrosion giving rise to excessive maintenance (Ref 1-4). Though such type of corrosion causes only a small metal loss and hence a small amount of corrosion product, this can still be sufficient to produce membrane fouling. The service experience from 24 SWRO plants confirms that there is an evident risk of corrosion if wrong steel grade is used for the high pressure piping. Neither 316L nor 317L possesses sufficient corrosion resistance. Not even highly alloyed grades like 2205 and 904L show reliable service performance. However, no corrosion has been reported for 254 SMO, which has been used in 13 full strength SWRO plants and several plants using high salinity (Ref 5). Recently, the failure investigation of a high pressure piping made of 904L from a major SWRO plant on the coast of the Mediterranean Sea was carried out. The piping had suffered extensive pitting and crevice corrosion due to inadequate corrosion resistance to the environmental conditions (Ref 6).

During the last two decades, there has been increasing trend toward the use of high corrosion resistance super-austenitic or super duplex stainless steels for SWRO high pressure applications, but they further add to the initial capital cost of the installation. The users of SWRO plants have been looking for corrosion free and economically viable alternative to high alloyed stainless steels in order to reduce the high cost of SWRO Desalination and prevent membrane fouling. The coated carbon steel piping system may be an economically viable alternative to costly high alloyed stainless steels like 254 SMO or similar grades and at the same time corrosion resistant if proved successful during actual plant operation. Keeping in view the above fact thermoplastic-coated steel pipes, fittings and test panels of different dimensions and coated on both sides were commercially obtained and were subjected to SWRO pilot plant and aggressive laboratory tests. The main objective of the work was to evaluate the high pressure performance of the thermoplastic-coated piping system under pilot plant operating conditions. It was further aimed to study the accelerated corrosion behavior of the system by carrying out salt spray test. As the SWRO system encounters many crevices, the performance of the coating under crevices was also tested. The mechanical testing on the coated steel samples was carried out under controlled laboratory conditions. The leachable organics

---

Mohammad Mobin, Department of Applied Chemistry, Faculty of Engineering & Technology, Aligarh Muslim University, Aligarh 202002, India. Contact e-mail: drmmobin@hotmail.com.

and inorganics in the test media were also monitored to establish the safety of the coating from health point of view.

The coating powder Plascoat PPA 571 (Ref 7) was chosen based on its properties as it has been designed to provide a long lasting and tough coating for mild steel piping. The thermoplastic-coated steel pipes are expected to combine the strength of steel and resistance of thermoplastic powder to perform satisfactorily in a vide variety of corrosive media. A survey of literature on thermoplastic coated steel pipes showed that no reference is available regarding their use in SWRO high pressure applications. However, products designated as TP-pipe system (a carbon steel piping system coated internally and externally with thermoplastic coating powder PPA 571) were found to be commercially manufactured by Alvenius Industrier AB Sweden (Ref 8). The TP-pipe system is claimed to be suitable for high pressure applications ranging from 25 to 70 bar which is generally encountered in SWRO plants. The system is further claimed to out performed stainless steel, when it comes to corrosion protection and service life and have found wide industrial applications such as leaching, process water, fire hydrant installations, potable and waste water and for highly corrosive media throughout the world (Ref 8).

2. Experimental

2.1 Coating

The thermoplastic-coated pipe system is a carbon steel piping system coated internally and externally with thermoplastic coating (coating powder Plascoat PPA 571). Pipe and fittings made of steel material approved for pressure vessel application are sand blasted with steel grit and then heated to approximately 250 °C. The coating is applied by dipping in a fluidized bed with thermoplastic powder or by electrostatic spraying depending upon the shape and size of the items to be coated. The recommended film thickness is 20-30 mils. The safe working temperature of the products in continuous air is 65 °C. The product has approval for potable water services from different international agencies.

3. Experimental Methodology

3.1 SWRO Pilot Plant Test

The Hollow fine fiber SWRO pilot plant was modified by introducing the thermoplastic piping products (diameter 25.4 and 31.75 mm) in feed and rejects streams (Fig. 1) and was operated continuously for 10 months. During the test, seawater feed and brine from SWRO membrane was passed through the piping at high pressure of about 70 bars. The typical composition of seawater feed is shown in Table 1. The water samples collected periodically from seawater feed, RO reject and RO product were analyzed to investigate any leaching from thermoplastic material. After completion of the test run, the coated pipes were taken out and physically examined.

Fig. 1 Photograph showing the SWRO pilot plant test unit modified with thermoplastic piping

Table 1 Typical composition of feed seawater

Parameters	
pH	8.20
Conductivity	61500 μS/cm
M. alkalinity	128 mg/L
Bicarbonate	156 mg/L
Chloride	23476 mg/L
Sulfate	3243 mg/L
Total hardness	7557 mg/L
Ca^{2+}	501 mg/L
Mg^{2+}	1531 mg/L
Total dissolved solids	44520 mg/L

Table 2 Rating of failure at scribed area [ASTM D1654-71a]

Representative mean creepage from scribe	
Millimeters	**Rating number**
Over 0	10
Over 0 to 0.5	9
Over 0.5 to 1.0	8
Over 1.0 to 2.0	7
Over 2.0 to 3.0	6
Over 3.0 to 5.0	5
Over 5.0 to 7.0	4
Over 7.0 to 10.0	3
Over 10.0 to 13.0	2
Over 13.0 to 16.0	1
Over 16.0 to more	0

3.2 Salt Spray Test

Salt spray tests were carried out using Q-Fog Cyclic Corrosion Tester CCT 600 from Q-Panel, USA following ASTM designation B117-90. Scribed and unscribed coated specimens were exposed to salt fog test for 30, 60, and 90 days, respectively. Mean creepage from the scribe was measured and rated as per ASTM D1654-71a (Table 2). The blisters appeared on the scribed and unscribed sides were also recorded.

3.3 Testing of Coating Under Crevice Former

3.3.1 Pilot Plant Test. To generate data about the performance of coating under crevices, coated steel coupons attached with crevice former assembly were fixed in a coupon holder

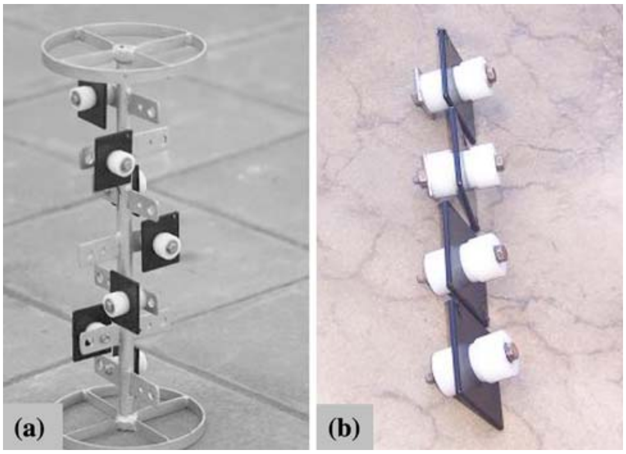

Fig. 2 Photograph of the assembly to be used for testing the coating under crevices in (a) pilot plant and (b) in laboratory

(Fig. 2a) and introduced in SWRO feed stream for a period of 6 months. After the required exposure, the coupon holder was taken out and the coupons were subjected to thorough examination. The following parameters were observed: (i) change in physical appearance, (ii) change in weight, (iii) adhesion loss, and (iv) blistering effect.

3.3.2 Laboratory Test. Coated steel coupons attached with the crevice formers (Fig. 2b) were immersed in a tank containing seawater. After 6 months, the coupons were taken out and subjected to thorough physical examination.

3.4 Mechanical Tests

3.4.1 Adhesion Test. To determine the adhesive strength of the coating coated steel samples were subjected to pull off adhesion test at room temperature following ASTM designation ASTM D4541-85 (Re-approved 1989). A portable pneumatic adhesion tester, Elcometer 110 PATTI from Electomer Instruments, England was employed in the test.

3.4.2 Bending Test. The test provides information on the ability of coatings applied on the substrate to resist cracking, disbonding, or other mechanical damage as a result of bending. The steel specimens coated with thermoplastic product were tested at room temperature using Mandrel Bend Machine. Prior to the bending, the thickness of the coating and steel substrate was also determined. The specimens were inspected visually for any visible defect. The specimens were then clamped in the holder and subjected to bending at room temperature. After completion of the test, the specimens were again inspected to see any cracking in the coating after bending. The machine was programmed to carry out the bending test by increasing the Mandrel radius step-by-step. The percent strain and degree per pipe diameter (°/PD) was calculated as given below:

$$\%\ \text{Strain} = \frac{100xt}{2R + t}$$

where t = steel thickness; R = Shoe Mandrel radius; and °/PD = % strain/0.87

3.5 Monitoring of Leachable Organics and Inorganics

3.5.1 Leachable Organics. To establish the safety of the coating from health point of view determination of leachable organics and inorganics was also carried out. The coated steel coupons were separately immersed in fixed quantity of demineralized water containing a residual chlorine concentration of 0, 1, and 10 ppm, respectively. After 48 h, the coupons were taken out and the remaining chlorine in the water samples was quenched using sodium thiosulfate. A portion of water sample was analyzed for volatile organics including THMs by GC/MS purge and trap following the standard method EPA 624. The other portion of the water sample was extracted with methylene chloride and analyzed quantitatively for semi-volatile organic compounds by GC/MS following standard method EPA 625. Leachable organics were also monitored in the water samples (SWRO feed, reject, and product) periodically collected from the pilot plant during the pilot plant testing of the thermoplastic products.

3.5.2 Leachable Inorganics. The coated steel samples were soaked in fixed amount of distilled water for time period 24 and 48 h maintaining a pH of 4 and 8. The samples were taken out and water was analyzed for possible leachable toxic trace metals such as As, Se, Hg, Cr, Cd, and Pb. The leachable toxic trace metals were also analyzed in the water samples (SWRO feed, reject, and product) periodically collected from the pilot plant during the pilot plant testing of the thermoplastic products. The trace metal analysis was carried out using GBC Avanta Sigma and Perkin Elmer AAnalyst-800 atomic absorption spectrophotometer.

The Hg in the water samples was analyzed by following cold vapor technique. As and Se were analyzed using hydride generation technique. Cd, Cr, and Pb in product water samples were directly analyzed by graphite furnace technique. These elements in feed and reject seawater were separated from seawater matrix by first extracting in an organic phase MIBK-APDC followed by stripping into 2 M HNO_3 before analyzing by GF-AAS.

4. Results and Discussion

4.1 SWRO Pilot Plant Test

The thermoplastic piping taken out after the exposure to pilot plant tests were subjected to thorough physical examination. The external coating did not show any change in physical appearance, adhesion loss, or blistering effect. To examine the integrity of the internal coating, the tubes were splitted. The internal coating was found covered with some dark brown products probably from the feed water and was easily cleaned with water. The coating after cleaning did not show any color change. A careful examination of the splitted tubes showed the presence of some round blisters on the internal surface of the tubes. The blister were broken initiating the corrosion of the underneath steel. The coating appears to be nonuniform over the weld seam. The photographs of the splitted tubes showing blister formation is shown in Fig. 3.

Blistering is one of the most common type of coating failure related to adhesion. The usual cause of the blistering is the penetration of moisture through the coating into the areas of poor adhesion. The moisture vapor may condense and form a liquid blister, or the vapor pressure of the moisture at the interface between the coating and the surface may be sufficient to lift the coating away from the substrate. Blisters are either formed from the substrate with the coating separating from the substrate or formed between coats where the top-coat separates from an under-coat. A number of conditions can cause

Fig. 3 Splitted view of the tubes showing blisters formation

Fig. 4 Photograph of the coupons taken after 30 days of exposure in salt fog chamber. Loss of adhesion at the scribed mark can be seen

blistering. It includes soluble pigments in the primer, soluble salts contaminating the substrate or contaminating the surface between coats of the coating or contamination of the surface by materials (oils, waxes, dust, etc.) that will not allow proper adhesion of the coating; selection of an improper primer for the surface; incompatible coatings; poor or inadequate solvent release by the coating. It appears that the coated steel pipes were already having areas of poor adhesion as a result of poor application of coating on relatively low diameter pipes allowing the penetration of moisture in that areas.

4.2 Salt Spray Test

Scribed and unscribed specimens exposed to salt fog were evaluated with respect to representative mean creepage from scribe and blistering. The typical photographs of specimens obtained after 30 days of exposure to salt fog tests are shown in Fig. 4 and 5 and the results are summarized in Table 3 and 4.

The representative mean creepage (from scribe) for the coating after 30 days exposure to salt fog is 12.79 mm giving a rating of 2. However, the coating did not show blistering on either side of the specimens. After 60 days of exposure to salt fog, the mean creepage is increased considerably (20.86 mm) giving a rating of zero. The coating also showed formation of blisters on either side of the specimens. The specimens exposed to salt fog for 90 days showed the formation of many blisters on either side. However, the blistering was more pronounced on the scribed side. The evaluation of unscribed samples exposed to salt fog also showed formation of blisters on the specimens.

The typical properties of Plascoat PPA 571 (Ref 7) showed that the coating was subjected to salt spray test following ISO 7253 designation. The result after 1000 h of exposure showed loss of adhesion <10 mm from scribe. During present

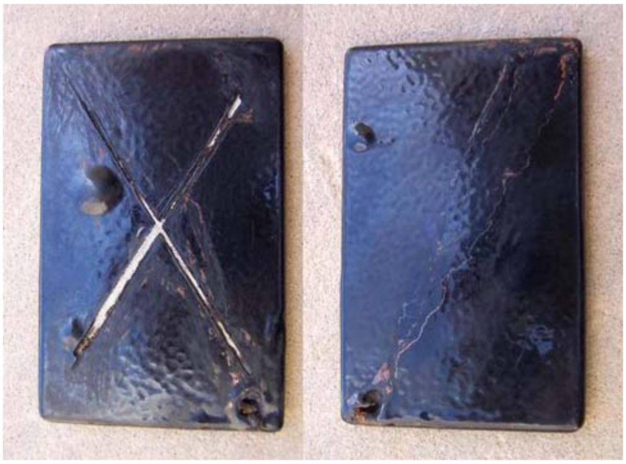

Fig. 5 Photograph of the coupon showing blister formation on the scribed and unscribed side. Coupons were taken after 60 days of exposure in salt fog chamber

Table 3 Salt spray test results—evaluation of scribed specimens

S. no.	Exposure period, days	Representative mean creepage from scribe, mm	Rating number	Remarks
1	30	12.79	2	No blistering on either side of the sample
2	60	20.86	0	Blistering on both sides of the sample
3	90	···	···	Blistering on both sides of the sample

Table 4 Salt spray test results—evaluation of unscribed specimens

Sample no.	Exposure period, Days	Number of blisters	Remarks
1	30	Nil	···
2	30	Nil	···
3	60	Nil	···
4	60	02	Blisters on one side of specimen
5	90	Nil	···
6	90	02	One blister on either side

investigation, the coating was subjected to salt spray test following designation ASTM B117 which is identical to ISO 7253 as both uses 5% aqueous solution of sodium chloride and operation of cabinet at 35 °C. The result after 30 days (720 h) of exposure showed loss of adhesion more than 10 mm from the scribe. Though the poor performance of coating under salt fog tests may not be denied, it may be noted that in different standards used to test the resistance of coating to salt spray (fog) tests pass/fail criteria is not defined. This is just a matter of agreement between concerned parties.

4.3 Testing of Coating Under Crevices

The coupons obtained after subjecting to crevice corrosion tests both in the pilot plant and laboratory were physically examined and photographed. Figure 6 shows the photograph of the coupons after crevice corrosion test in the laboratory. The results are summarized in Table 5 and 6. In majority of the samples exposed to crevice corrosion test, the coating did not show any visible change in physical appearance and the performance of coating under the crevice was satisfactory. However, blisters were formed on both sides of the samples, thus putting a question mark on the adhesion property of the coating.

Fig. 6 Photograph of the coupons after crevice corrosion test in the laboratory. Absence of corrosion under crevice area can be seen

4.4 Adhesion Test

During the test, at one location a plug of the coating was detached from the substrate at 999.8 psi (Fig. 7). This indicated

Table 6 Results of crevice corrosion test in the laboratory

Sample no.	Change in physical appearance	Effect under crevice area	Blistering effect
1	Nil	Nil	Blister on both the sides
2	Nil	Nil	No blistering
3	Nil	Nil	Blister on one side
4	Nil	Nil	Blister on one side
5	Nil	Nil	Blister on one side

Fig. 7 Photograph showing the coated panel after pull-off adhesion test. A plug of coating detached from the substrate can be seen

Table 5 Results of the crevice corrosion test in the pilot plant

Sample no.	Initial weight, g	Final weight, g	Weight change, g	Change in physical appearance	Effect under crevice area	Blistering effect
1	70.0537	70.1520	+0.0983	Nil	Nil	Blister formation on one side of coupon away from crevice area (near the edge)
2	70.1183	70.0534	−0.0649	Nil	Nil	Blister formation on one side of coupon away from crevice area (near the edge)
3	70.3747	70.3973	+0.0226	Nil	Nil	Blister on both the sides of coupon away from crevice area
4	69.7721	69.7894	+0.0173	Nil	Corrosion on one side	Blister on both the sides of coupon away from crevice area
5	70.0392	70.0588	+0.0196	Nil	Nil	Blister on both the sides of coupon away from crevice area
6	70.2183	70.2342	+0.0159	Nil	Nil	Blister on both the sides of coupon away from crevice area
7	70.5026	70.5406	+0.0360	Nil	Nil	Blister on both the sides of coupon away from crevice area

that the strength of adhesive was sufficient to pull off the coating from the substrate. However, at other two locations, the pull stub was detached at the coating/pull stub interface at 1399 and 1600 psi, respectively, confirming that the bonding between the metal substrate and coating was more than the coating and pull stub. This again shows that coating was not uniformly applied on the substrate.

Fig. 8 Photograph showing the coated panels after bending test

4.5 Bending Test

The photograph of samples obtained after subjecting to bending is shown in Fig. 8. The visual examination of samples did not show any defect at the bending site. The calculated values of % strain and °/PD are as follows:

(i) When using Shoe Mandrel radius of 87 mm

% Strain = 4.10
°/PD = 4.71

(ii) When using Shoe Mandrel radius of 95.2 mm

% Strain = 3.76
°/PD = 4.32

Table 7 Results of leachable organics—laboratory test

	Concentration, ppb		
Organic pollutants	**Without chlorine**	**1 ppm chlorine**	**10 ppm chlorine**
Trihalomethanes (THMs)			
Chloroform	ND	ND	ND
Dichlorobromomethane	ND	ND	ND
Dibromochloromethane	ND	ND	ND
Bromoform	ND	ND	ND
Total trihalomethanes (TTHMs)	ND	ND	ND
Purgable organic compounds	ND	ND	ND
Semivolatile organic compounds	Traces of phenol 2,4-bis(1,1 dimethyl ethyl)		

ND, not detected

Table 9 Results of leachable inorganics—laboratory test

			Leachate after 24 h		Leachate after 48 h	
Parameters	**Unit**	**MLC, ppb**	**pH = 4**	**pH = 8**	**pH = 4**	**pH = 8**
Arsenic	ppb	50	0.30	ND	0.30	ND
Selenium	ppb	10	ND	ND	ND	ND
Mercury	ppb	1	ND	ND	ND	ND
Lead	ppb	50	ND	ND	ND	ND
Cadmium	ppb	5	0.60	0.50	0.70	0.50
Chromium	ppb	50	ND	ND	ND	ND

ND, not detected; MCL, maximum contaminant level in drinking water

Table 8 Results of leachable organics—pilot plant test

	Sampling date														
	Second month			Third month			Fourth month			Sixth month			Tenth month		
Parameters	**RO feed**	**RO reject**	**RO product**	**RO feed**	**RO reject**	**RO product**	**RO feed**	**RO reject**	**RO product**	**RO feed**	**RO reject**	**RO product**	**RO feed**	**RO reject**	**RO product**
THMs (ppb)															
Chloroform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dichlorobromomethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibromochloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromoform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total THMs	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Purgable organic compounds, ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Semivolatile organic compounds, ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total organic carbon (TOC) determined as NPOC, ppm	1.5	1.7	1.0	1.0	1.2	<0.5	NA	NA	NA	NA	NA	NA	NA	NA	NA

ND, not detected; NPOC, non-purgable organic carbon; NA, not analyzed

Table 10 Results of leachable inorganics—pilot plant test

	Sampling date											
	Second month			Fourth month			Sixth month			Tenth Month		
Parameters	**RO feed**	**RO product**	**RO reject**	**RO feed**	**RO product**	**RO reject**	**RO feed**	**RO product**	**RO reject**	**RO feed**	**RO product**	**RO reject**
Arsenic	1.0	ND	1.3	2.0	ND	2.2	1.9	ND	2.2	1.1	ND	2.3
Selenium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mercury	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead	1.7	0.2	2.8	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium	0.5	ND	0.8	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND, not detected

4.6 Monitoring of Leachable Organics and Inorganics

Since the coating under evaluation is an organic compound, there is possibility of degradation or leaching of coating or a part of it with exposure to RO feed, reject, or product water under severe pilot plant test condition. The results of the leaching tests are shown in Table 7 and 8. The results did not show the leaching of organic pollutants either during laboratory test or pilot plant testing.

The results of leachable inorganics determined during the leaching tests in laboratory as well as the analysis of water samples obtained during the pilot plant testing of the coating is listed in Table 9 and 10. The results of the analysis did not show the leaching of inorganic pollutants either during laboratory test or pilot plant testing.

5. Conclusions

1. The coated piping system subjected to 10 months pilot plant test showed the formation of some blisters on the internal surface. The blisters were broken causing the initiation of corrosion of underneath steel. The internal coating also showed failure on the weld seam at one point.
2. On 30 days (720 h) exposure to salt fog test, the mean creepage from the scribe is more than 10 mm which is further increased on increasing the exposure period. The observed values are significantly higher than the values mentioned in the product data sheet. This shows that coating was poorly applied on the test coupons. The scribed and unscribed samples also showed the formation of blisters on either side of the samples.
3. The performance of coating under crevices, in general, was satisfactory. However, blisters were formed on either side of the samples.
4. The results of adhesion tests showed nonuniform bonding between the coating and the metal substrate. The bending test showed no defect at the bending site.
5. The chemical analysis results did not show the leaching of any organic or inorganic pollutants from the coating.
6. The coated steel pipes appears to have areas of poor adhesion as a result of poor application of internal coating on relatively low diameter pipes allowing the penetration of moisture in that areas and subsequently leading to blister formation.

6. Recommendations

1. Except the formation of blisters and poor rating in salt spray tests, which may be attributed to the poor application of the coating, the performance of coating under crevices, results of flexibility test and leaching of organic or inorganic pollutants with exposure to RO feed, reject or product water under severe pilot plant test condition appears to be quite satisfactory. These properties qualify thermoplastic-coated steel pipes as a suitable choice for high pressure SWRO applications.
2. Keeping in view the formation of some blisters on the internal surface of pipes and test coupons during the present testing, it is recommended to test the coated pipes in commercial SWRO plants before their final selection as candidate material for high pressure SWRO application. In commercial SWRO plants, the diameter of pipes is higher than the pilot plant, this will address the drawback associated the application of coating on smaller diameter pipes.

References

1. A. M. Hassan, S. Al-Jarrah, T. Al-Tohibi, A. Al-Hamdan, L. M. Bakheet, and M. Al-Amri, Performance Evaluation of SWCC SWRO Plants, *Desalination*, 1989, **74**, p 37
2. J. Carew, M. Abdel-Jawad, M. Julka, and Y. Al-Wazzan, Performance of Materials used in Seawater Reverse Osmosis Plants, *Desalination*, 1989, **74**, p 85
3. M.F. Lamendola and A. Tua, Desalination of Seawater by Reverse Osmosis, the Malta Experience, *Desalinat. Water Reuse*, 1995, **5**(1), p 18–22
4. A.U. Malik, I. Andijani, M. Mobin, F. Al-Muaili, and M. Al-Hajri, Investigating Weld Leeks at Medina-Yanbu Plants, *Desalinat. Water Reuse*, 2005, **14**(4), p 22–26
5. J. Nordstrom and J. Olsson, “Which Stainless Steel to Use for SWRO Plants?” Avesta AB, S-774 80, Avesta, Sweden
6. J. Olsson and M. Snis, Don’t Repeat mistakes! An SWRO Plant Case Study, *Proc. IDA World Congress on Desalination and Water Re-use*, SP05-036, Singapore, Sept 11-16, 2005
7. Plascoat PPA 571, “Product Data Sheet,” Plascoat systems Ltd, Surrey, GU9 9NY, UK
8. TP-pipes, “Product data sheet,” AB Alvenius Industrier, Eskilstuna, Sweden