Corrosion Studies of a Few Aluminium, Copper, Nickel and Iron Base Alloys in Salt Water

P R Shibad and J. Balachandra*

Metallurgy Division, Bhabha Atomic Research Centre, Bombay-85; Now at Indian Institute of Science, Bangalore*

(Received and accepted Sept. 1976)

A few aluminium, copper, nickel and iron base alloys have been subjected to corrosion tests up to 15 days in 3% NaCl solution and synthetic sea water under various conditions of experiment. Anodic polarisation studies reveal that there is no passivity but dissolution and the general pattern of the cathodic polarisation curves is observed to be the same for all the conditions of experiments studied. There is slight pitting observed for aluminium alloys while copper, nickel and iron base alloys do not exhibit pitting tendency. Aluminium brass, nickel-free austenitic stainless steel and Hastelloy X merit consideration for use in salt water service.

Extensive survey [1—6] is available in the field of selection of materials for condenser tubes and heat exchangers in desalination and salt water service. The choice of various copper, titanium and iron base alloys of component materials in desalination plants in salt water of varying degree of corrosivity has been pointed out earlier [6]. A large number of investigations has been carried out on the corrosion behaviour of various materials in these applications. This has enabled corrosion technologists to explore the corrosion behaviour of various materials that have potential application for these services.

Specifically Al-0.7% Be, Al-0.4% Zr alloys, aluminium brass, Cu-1.7% Be-0 3% Co (Be-Cu alloy) as-received and heat treated at 800°C for 4 hours and water quenched, extruded Cu 90%-Ni 10% at 920°C and cold drawn afterwards, nickel cast iron, nickel-free austenitic stainless steel and Hastelloy X have been studied for their corrosion behaviour in 3% NaCl and synthetic sea water under different conditions of experiment similar to those reported earlier [6]. The data obtained were compared with those for Al-1S, pure copper and nickel.

EXPERIMENTAL

Aluminium-base alloys were melted in an induction furnace, cast and cold rolled. Aluminium brass and Cu-1.7% Be-0.3% Co alloy specimens were obtained in the rolled condition while Cu 90%-Ni 10% were extruded into billets at 920°C and cold drawn afterwards. Pure electrolytic copper and nickel and Al-1S were obtained in the form of sheet. Nickel cast iron specimens were cut from a cast rod 2.5cm dia. and nickel-free austenitic stainless steel and Hastelloy X specimens were obtained in rolled condition. The specimens were degreased in acetone and benzene, dried, weighed and their surface areas measured. They have been immersed in 3% NaCl (AR Grade) solution prepared using double distilled water and in 3% NaCl soultion at pH 3 and pH 10, and in synthetic sea water at 28°C. and 101°C. Composition of alloys used is given in Table I and of sea water is mentioned in our earlier paper [6]. The corrosion testing in medium under boiling conditions have been carried out under reflux in a conical flask, fitted with a Leibig condenser with circulating cooling water. The volume of the corrodent used is 20 ml/cm² of the area of the specimens immersed. The chemicals used for preparing synthetic sea water were of the AR Grade. The specimens have been hung from the hooks of the glass rod which is completely immersed in the corrodent. At the end of the tests, the specimens were thoroughly washed first in running tap water and then in distilled water, degreased in acetone, dried and weighed. The weight losses or gains of the specimens are expressed as mils per year penetration based on 15 days' test. Potentiostatic polarisation studies on the anodic and cathodic behaviour of these materials in 3% NaCl and synthetic sea water have been carried out at 28°C. Platinum is used as an auxiliary electrode and potentials have been measured against saturated calomel electrode. The potentials have been scanned at the rate of 50 mV per minute.

RESULTS AND DISCUSSION

1. Weight change determination

The behaviour of twelve materials under twelve different environmental conditions has been given in Table-2. From the data it is possible to screen the materials as to their corrosion characteristics in the media studied. This gives an overall picture of their behaviour to the corrosion engineer.

Amongst the aluminium-base alloys tested in 3% NaCl solution (pH is 6.4), the Al-Be and Al-Zr alloys have lower corrrsion rates than Al-IS at room temperature ; reverse is the case in boiling 3% NaCl solution. Actually, there is considerable weight gain. These alloys are found to have lower corrosion rates in 3% NaCl adjusted to pH 3 at 28°C than Al-IS. In 3% NaCl solution and synthetic sea water under stirred and ultrasonically stirred conditions at room temperature the corrosion rate is lower In 3% NaCl solution adjusted to pH 10 at 28°C, the corrosion rates of the two alloys and Al-IS are about the same. But in boiling 3°/$_c$ NaCl (pH adjusted to 10 at 28°C) the corrosion rate of Al-0.4°/$_o$ Zr alloy is lower than that of Al-IS while that of Al-0.7$_0$/° Be alloy is higher. At slightly elevated temperatures in 3°/$_o$ NaCl solution and synthetic sea water, the corrosion rate of Al-0.4°$_o$ Zr alloy is much higher than that of Al-IS while that of Al-0.7°/$_o$ Be alloy is higher under these conditions in 3°/$_o$ NaCl solution ; in synthetic sea water under similar conditions it is of the same order as that of Al-IS (though a weight gain). These experimental aluminium-base alloys are inferior to Al-2S, 3S 24S, 52S, 57S and Al-9°/$_o$ Si-1% Ni with and without 1°/$_o$ Mg in 3$_o$/° NaCl at 28°C almost in contrast to the case under stirred condition[8,9]

In the case of copper-base alloys, aluminium brass exhibits highest corrosion rate in 3% NaCl solution both in stirred and unstirred condition amongst the three copper alloys tested and mentioned in other papers [7,9,10]. However aluminium brass is unaffected in synthetic sea water (pH 8.2) at room temperature. The corrosion rate of aluminium brass is lower and of the same order as that of Cu 90% – Ni 10% in boiling 3% NaCl solution unlike Cu, Cu-Be-Co alloys. In each case stirring of the solution generally causes a higher rate of corrosion. Cu 90%–Ni 10% alloy shows highest rate of corrosion in 3%NaCl ultrasonically stirred amongst the copper-base alloys. Ultrasonic stirring of 3% NaCl solution or synthetic sea water causes higher rate of corrosion for the copper-base alloys except in the case of aluminium brass, where the corrosion rate is lowest in synthetic sea water under stirred condition. The corrosion rates for the as-received and heat treated Cu–1.7% Be–0.3% Co alloy are of the same order except in 3% NaCl stirred ultrasonically where the heat treated specimen has high corrosion resistance than the as-received one. The corrosion rates of In 838 and In 848 alloys are lower than those for aluminium brass, Cu-1.7% Be-0. 3% Co and Cu 90%–Ni 10% alloys, In 848 being the most superior in 3% NaCl solution with and without stirring condition [6]. In 3% NaCl solution adjusted to pH 3 at 28°C, the corrosion rates are generally higher. In boiling solution however there is a small increase in the corrosion rate of aluminium brass; that of the other alloys and copper increases appreciably. At pH 10 both at 28°C and in boiling solution the corrosion rates are fairly low in all cases.

In the case of iron–base alloys the corrosion rate is slightly lower for Ni cast iron compared with nickel-free austenitic stainless steel in 3% NaCl solution at 28°C. while the reverse is the case observed in synthetic sea water at 28°C. Boiling test at 101°C in synthetic sea water causes nickel-free stainless steel to exhibit maximum corrosion rate value of 16.99 mpy compared with other conditions of experiment. The corrosion rate is of the same order as that at pH 3 in 3% NaCl solution at boiling temperature, Another interesting observation is that this nickel-free stainless steel is uneffected in 3% NaCl solution when ultrasonically tested, while nickel cast iron exhibits a high rate of corrosion viz. 51.42 mpy. 304 SS behaves better than nickel cast iron and nickel-free stainless steel in 3% NaCl with and without stirring.

Nickel and Hastelloy X are unaffected in 3% NaCl soultion and in synthetic sea water under stirred condition. Hastelloy X shows higher rate of corrosion of 2.59 mpy in 3% NaCl solution under ultrasonically stirred condition compared with pure nickel which is unaffected, Hastelloy X shows a slightly higher rate of corrosion than Hastelloy C and Inconel [8].

It is interesting to note that none of the copper, iron and nickel base alloys pit in salt water under various conditions of experiment, but in the case of aluminium-base alloys slight pitting is observed. In the case of Cu–1.7% Be-0.3% Co alloys in NaCl solution at pH 3 at boiling temperature it is observed that the specimens are reddish in colour, while in the case of nickel cast iron there is a reddish colour in boiling synthetic sea water due to dissolution of iron and probable deposition on the surface, where-as in plain 3% NaCl solution it is not observed to that extent as is evident from the low corrosion rate of 0 54 mpy as against 2.9 mpy in boiling synthetic sea water.

In the case of Al, Fe and Ni base alloys, there is weight gain observed in a few conditions of experiment due to film formation during the corrosion process, while in the case of all the copper-base alloys [6-8-9-10] there is no pitting tendency and weight gain of the specimens after corrosion. This shows that the corrosion of copper-base alloys in salt water is one of uniform dissolution.

Polarisation studies

Potentiostatic polarisation studies on the anodic and cathodic behaviour of these materials have been carried out in 3% NaCl solution at 28°C, 3% NaCl solution at pH 3 and pH 10 at 28°C and in synthetic sea water at 28°C The following inferences have been drawn from the studies 1. In the case of Al-IS, Al–0 7% Be and Al–0.4% Zr alloys the corrosion currents observed are smaller in synthetic sea water than in 3% NaCl solution which is reflected in weight loss measurements. At pH 3, the corrosion currents are much higher than those reported for pH 10 which is also reflected in weight loss measurements. The anodic polarisation shows that the materials show simple dissolution without any passivation. The general pattern of the cathodic polarisation curve is the same in all the concentrations of solutions

2. In the case of Cu, Fe-base alloys and Hastelloy X, the conclusions are the same as those observed in the case of aluminium-base alloys. Cu–1.7% Be–0.3% Co alloys (as received and heat treated) exhibits slow increase in anodic potentials after 10^{-3} amp/cm^2. The cathodic polarisation curve has the same pattern of initial reduction between 10^{-6} to 10^{-4} amp/cm^2 as other alloys. In 3% NaCl solution during anodic polarisation, it is noted that the corosion of Cu-Ni alloy decreases at 4×10^{-3} amp/cm^2 and thereafter increases from 3×10^{-3} amp/cm^2 and in synthetic sea water at 9×10^{-4} amp/cm^2, the corrosion currents remain almost constant from + 100 mV to + 400 mV and thereafter increases.

CONCLUSIONS

1. Amongst the various aluminium-base alloys tested in 3% NaCl solution at 28°C, the Al-0.7% Be and Al-0.4% zr alloys have lower corrosion rates than Al-1,S while the reverse is the case observed under boiling conditions. These alloys have low corrosion rates in 3% NaCl solution and synthetic sea water under stirred conditions. There is slight pitting observed in these alloys after corrosion.

2. Aluminium brass is unffected in synthetic sea water at 28°C and its rate is reduced at boiling temperature unlike pure copper, Cu–1.7%Be-0.3% Co Cu 90%-Ni 10% alloys. It has the lowest corrosion rate in synthetic sea water under stirred condition. There are no signs of pitting or dezincification or corrosion. The corrosion rates in the case of Cu-1.7% Be-0.3% Co alloys are almost of the same order except for the as-received specimen where the corrosion rate is ten times higher than the heat treated one in 3% NaCl solution under stirring condition.

3. Nickel-free austenitic stainless steel exhibits maximum corrosion resistance in boiling synthetic sea water compared with the other copper base alloys. It is unaffected in 3% NaCl solution under ultrasonically stirred condition. Nickel and Hastelloy X are unffected in 3% NaCl soultion and synthetic sea water under stirred conditions. There are no signs of pitting or corrosion in the nickel and iron base alloys.

4. Anodic polarisation shows that these alloys do not exhibit passivity but dissolution. The general pattern is the same for all the conditions of experiment for the cathodic polarisation curves. In many cases where the corrosion rate is higher than the othe other alloy, higher current densities are observed for the anodic polarisrtion curves.

5. Aluminium brass, nickel-freeaustenitic stainless steel and Hastelloy X merit consideration for use in salt water service.

Acknowledgements The authors wish to thank Head, Metallurgy Division, BARC for his encouragement throughout the course of this investigation.

Table-I Composition of the alloys in weight percent

Alloy	Cu	Zn	B	Al	N	Ni	W	Zn	Si	Mn	Cr	Fe	Co	C	Mo	S
Al-brass	76	22		2												
In 838	Bal					18.28				0.47	0.13	1.19		0 03		
In 848	Bal					32.99				0.75	0.10	1.34		0.03		
Ni-free austenitic stainless steel			1 ppm		0.53					17.55	17.71	Bal.		0.08		0.019
Cu 90%-Ni 10%	8.8					10.25		0.02		0.25		1.27				
Ni cast iron						13.6			2.01	1.14	1.99	Bal		1.8		
Hastelloy X						Bal.	1	1		1	22	18.5	1.5	0.02	9	

Table-II Corrosion rates of various materials of interest in salt water under various conditions of experiment

Conc	Temp	Corrosion rate mils per year (mpy) on the basis of 15 days' test											
	oC	Alls	Al-Be	Al-Zr	Al brass	Cu-Be-Co as recd	Cu-Be-Co HT	Cu-Ni		Ni free S. S.	Ni cast iron	Haste-lloy X	Ni
1	2	3	4	5	6	7	8	9	10	11	12	13	14
3% NaCl	28	8.17	1.4	2.33*	1.45	0.68	0.81	0.48	0.54	0.08	0.025*	0.23	0.08
,,	101 (B.Pt)	4.60	41.95*	22.82*	0·94	1.70	1.40	0.83	4.41	1.68	0.54	1.57	—
,, pH 3	28	12.65*	5.13*	3.79*	2.36	3.37	3.87	8.68	9.47	1.05	2.74	0.044	2.51
,, ,,	101	9.52	10.31	4.61	3.22	14.79	15.26	39.63	38.00	20.18	7.22	—	—
,, pH 10	28	0.34	0.51	0.21	0.49	1.01	0.56	0.61	0.66	0.07	0.58	0.15*	0.05
,, ,,	101	10.16	23.40	5.68	0.15	2.20	2.30	0 05	4.92	0.27*	0.88	—	—
Synthetic sea water	28	0.10	0.20*	0.09	—	0.73	0.64	0.83	0.67	0.102	0.84	—	0.07
,,	101	5.93*	51.80*	31.21*	0.42	0.59	0.78	2.96	0.39	16.99	2.92	0.58	0.09*

1	2	3	4	5	6	7	8	9	10	11	12	13	14
3% NaCl, stirred.	28	16.64	0.55	—	4.56	3.52	2.96	1.58	5.98	0.26	7.29	—	—
Synthetic sea water, stirred	28	0.35	0.70	0.32	0.48	1.89	1.83	0.72	2.83	0.25	2.33	—	—
3% NaCl stirred ultrasonically (6 hours test)	28 To 60	13.76	47.39	136.14	2.50	19.41	1.93	94.72	16.53	—	51.42	2.59	—
Synthetic sea water stirred ultrasonically (6 hours test)	28 To 60	100.48	9.89*	64.23	10.54	6.79	7.76	34.14	22.40	4.20	52.42	2.59	—

* weigt gain
—No weight loss

REFERENCES

1. R.M. Ahlgren, Materials Protection, (Oct. 1969)31
2. K.D Efird and D.B. Anderson, ibid. Nov 75
3. L. Martin, "Corrosion resistance of copper base alloys"– presented at the 13th Annual Conference of Metallurgists, August 1974, pp. 25-28.
4. J Balachandra, J. Inst. Engineers (India) part CH, 52 (1972) 72
5. "Selection of materials for large desalination plants"– International Nickel Co., Mill Bank Thames House, London SW 1.
6. P.R. Shibad and J. Balachandra, "Corrosion studies of Cu-Ni alloys and ferritic steel in salt water for desalination service"–BARC-805 (1975).
7. F.L. Laque, "Corrosion by sea water–Behaviour of metals and alloys in sea water", in "The Corrosion Hand–book" by H.H Uhlig, (1948, John Wiley and Sons Inc). p. 383.
8. P.R. Shibad and J. Balachandra, Anti–Corrosion Methods and Materials, (Feb 1968) 16.
9. P.R. Shibad and J. Balachandra, J. Electrochem. Soc. India 20(1971) 58
10. P.R. Shibad and J. Balachandra, Anti-Corrosion Methods and Materials, (Feb. 1967) 10

Asian Paints make
the widest range of
decorative and
industrial paints



ANY SURFACE THAT NEEDS PAINTING NEEDS asian paints