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CORROSION SCIENCE AND ENGINEERING

ATMOSPHERIC CORROSION OF 3004 ALUMINIUM ALLOY, PHOSPHOR BRONZE AND α- BRASS

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ABSTRACT

The corrosion rates of commercially available 3004 aluminium alloy, 70/30 brass and phosphor bronze were determined by exposure in the tropical marine atmosphere of Mandapam Camp. Weight-loss measurement was employed in computing the corrosion rates. The monthly corrosion rate of brass and phosphor bronze, and the quarterly corrosion rate of aluminium alloys were in line with the aggressiveness of the environment decided by the salinity value, temperature and humidity. The corrosion products formed on all the three alloys tested were compact and adherent. The direct attack of pollutants on the metals for further corrosion was hindered by the presence of these layers, and their protective nature was explicit from the exponential decrease of corrosion rates with time. In the high chloride containing atmosphere, the protection offered by the corrosion product on 3004 aluminium alloy was not so effective as that on the copper base alloys.

Key Words: Tropical-marine atmosphere, atmospheric corrosion, 3004 Al alloy, α-brass, phosphor bronze

INTRODUCTION

Whereas the literature of metals and alloys in atmosphere is mainly focussed on their general corrosion rate, much emphasis on other forms of corrosion leading to non-reliability of structures is generally lacking.

This necessitates more fundamental studies and field tests on the metals and alloys of interest. The computer aided design will be valid only if the reliability of the metallic system in the environment is known to highest accuracy. Instantaneous measurement of different types of corrosion by electrochemical techniques is vastly developed. Still, augmentation of these results by field exposure proves most reliable for heavy engineering systems like the nuclear power stations. For decades, from the time when corrosion was identified as a problem, the natural marine atmosphere serves as representative aggressive environment to evaluate the corrosion resistance of the newly developed metals and alloys.

The tropical-marine environment prevailing at Mandapam Camp, has proved to be one of the most aggressive atmospheres in the world. Atmospheric corrosion studies have been conducted on a variety of metals [1].

The present study evaluates the corrosion rate of 3004 aluminium, 70/30 brass and phosphor bronze by weight loss measurement over a period of two years.

MATERIALS AND METHODS

The alloys used in the present study were commercial grade, available in sheet and rod forms. The nominal composition and the analysis are presented in Table-I.

Standard panels of 150 x 100 mm size were cut from 2 mm thick, 2 x 1 m rolled 3004 aluminium alloy sheet, and 1.6 mm thick, 1 x 1 m rolled 70/30 brass sheets. Phosphor bronze, received in the form of 3 mm dia. drawn wire, was cut into 150 mm long rods. The defect-free samples were mechanically polished to have reproducible mirror polish. These were degreased and weighed to an accuracy of 10^{-4} g. Sufficient numbers of panels were exposed on the standard exposure racks erected at the test site. Another set of panels was also exposed inside a room-sized Stevenson Chamber located at the exposure yard. Triplicate samples were removed each time from the exposure, derusted in the respective standard solutions [1], dried and weighed accurately. Visual observations on the panels were also recorded during the exposure period.

Table I : **Composition of alloys**

Alloys	Nominal composition	Analysis
Brass	Zn: 30 wt%, Cu: Balance	Zn: 51.5 wt% Cu: Balance
3004 Al Alloy	Mn: 1.2 wt%, Mg: 1.0 wt% Al: Balance	Mn: 1.05% Mg: 1.12% Al: Balance
Phosphor bronze	P: 0.5 wt%, Sn: 5 wt% Cu: Balance	P: 0.4% Sn: 5% Cu: Balance

THE SITE

The exposure yard is located on the shore of Bay of Bengal in the Gulf of Mannar, 30m away from the water line and 3m above the mean sea level. The longtitude and lattitude of the site are 79° East and 9.2° North. Meteorological data for the site, like minimum and maximum temperature, sunshine hours, percentage relative humidity, rainfall, wind direction and velocity, salinity, sulphur dioxide content and dust content were recorded regularly using respective gauges supplied by Meteorological Centre, Pune.

RESULTS AND DISCUSSION

Monthly averages of the daily recorded meteorological data are presented in Figs. 1(a) and 1 (b). The lowest temperatures were recorded during

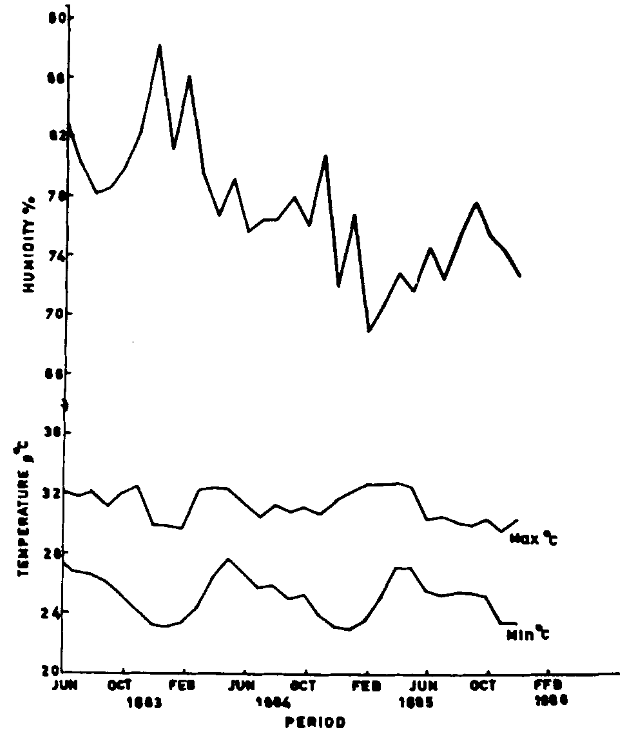

Fig. 1(a): Meteorological Data

the months of December and January and the maximum temperatures were observed during the months of April and May for every year. The temperature cycle was almost the same for each year. The relative humidity of the site was always higher than 65% with a maximum value of 84% during the months of June, July and August. Heavy rainfalls were recorded during the northeast monsoon periods, i.e. from October to February. The southwest monsoon, prevailing from March to September rendered occasional and lower rainfall. The location of the exposure yard admits the wind directly from the sea only during the southwest monsoon periods. During northeast monsoon period, the wind from Palk Strait has to cross the land about one and a half kilometers to reach the exposure yard. So, the season principally decides the wind direction and hence the salinity value at the site. The presence of shallow water along with the submerged rows of rocks in front of the exposure yard is the reason for the splash and carry-over of a considerable quantity of seawater particles by the high velocity wind during the southwest monsoon period. The higher salinity value of the site is in concurrence with the higher wind velocity recorded during the months of June, July and August (southwest monsoon period). Screening effect on the salinity by the rainfall can be noted from the lower salinity value for August 1984.

Brass

Monthly and cumulative corrosion rates of brass panels exposed in open as well as under sheltered condition in Stevenson Screen were evaluated, and are presented in Fig 2. Under both conditions, the monthly corrosion rates were decided by the combined effect of meteorological parameters prevailing at the site. Wide variation was experienced under open condition than under sheltered condition. Visual observation on the panels revealed that for the initial period of up to two months, corrosion was almost general with the appearance of dark brown colour on the panels. After

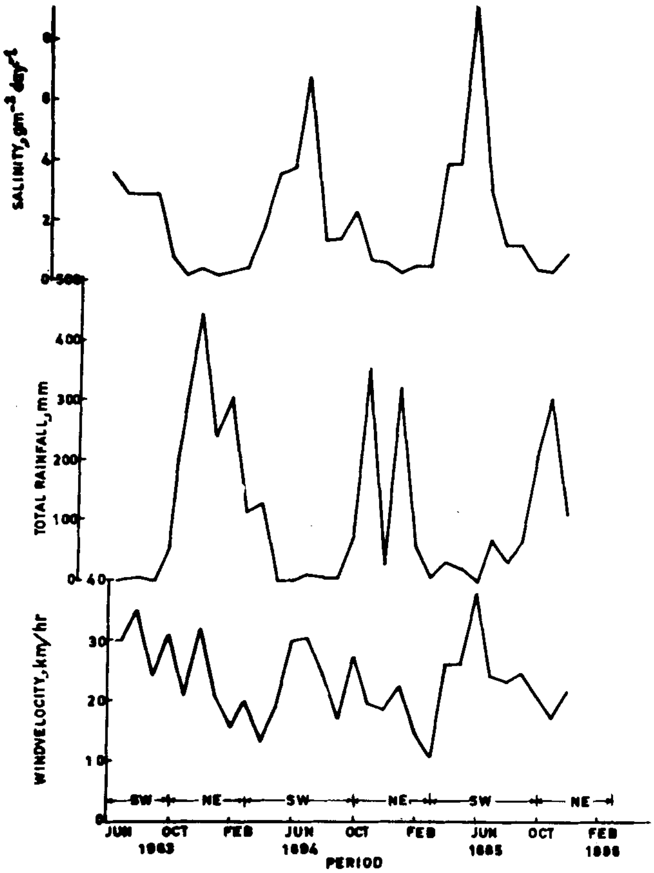

Fig. 1(b): Meteorological Data

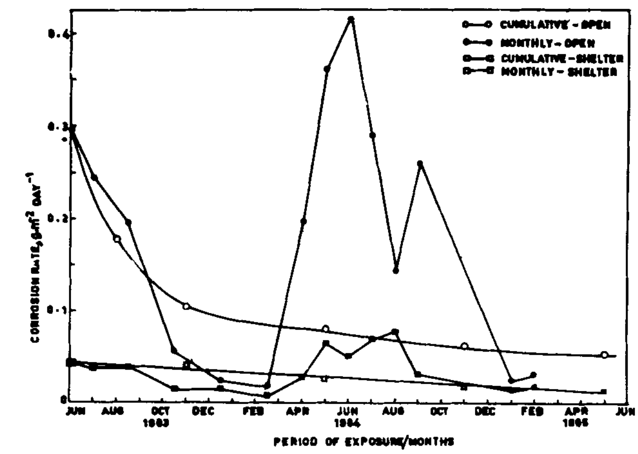

Fig. 2. : Corrosion rate vs period of exposure for 70/30 brass exposed in open atmosphere and under sheltered conditions

this period, the panels started showing white spots characteristic of zinc oxide and other compounds of zinc, on the reddish matrix. Till the termination of study for 2 years, no characteristic colour of copper compound was observed on the plates exposed on open, against the observation of greyish green reported elsewhere [2]. Their observation may be due to the presence of low salinity value and lower dezincification rate of the brass panels. This special dezincification of brass will be dealt with in the future publication. The maximum corrosion rate observed during the months of May, June and August was due to the combined effect of high salinity value and high temperature of the atmosphere. The lower values obtained during the months of December and January were due to the low aggressive nature of the environment combined with thorough washing of the panels by the heavy rainfalls. The cumulative corrosion rate of brass exposed in open condition decreased exponentially while that of panels exposed under sheltered condition decreased linearly up to a period of one and a half years. Plot of the square of weight-loss against time gives a straight line relation suggesting that the corrosion product formed on the panel protected the metal and further corrosion was taking place by diffusion of reactant through the product film. The lower corrosive environment prevailing inside the Stevenson Screen restricted the rate of formation of the product over the metal surface. Hence, a lower linear rate was observed up to a period of 1½ years. After this period, the linearity changes since the products formed on the panels prevent direct contact of metal surface with the environment. (The monthly variations were not reflected upon the cumulative rate because of the existence of undisturbed initial film combined with lower aggressiveness of the environment).

Phosphor bronze

Phosphor bronze rods were exposed under open condition at the shore site for monthly and cumulative corrosion rate evaluation. The results are presented in Fig 3. The results are similar to that of brass exposed in

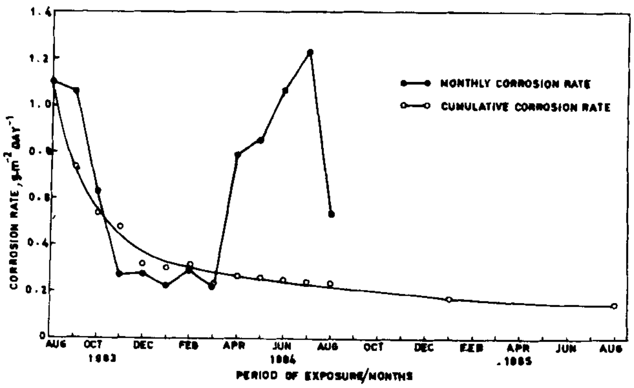

Fig.3 : Corrosion rate vs period of exposure for 5% phosphor bronze exposed in open atmosphere

open exposure yard. For the initial three to four months, dark brown corrosion product was observed. After this period, the product became bluish green. Spectacular, adherent bluish green product was observed on the (phosphor-bronze) rods exposed for one year and above.

The highest and the lowest monthly rates of this alloy during the months of July 1984 and January 1985 respectively show the variation in the aggressiveness of the environment due to the quantity of chloride ions present. The exponential decrease of cumulative corrosion rate indicates the protection offered by the tenacious and adherent corrosion product formed on the surface.

Aluminium alloy

The very low corrosion rate of aluminium and its alloy posed some difficulty in accurate determination of monthly corrosion rates, especially during the lean period. The quarterly, half-yearly and annual corrosion rates along with cumulative corrosion rates for 2 years for the aluminium alloy 3004 are presented in Fig 4. The corrosion of aluminium alloy initiated with

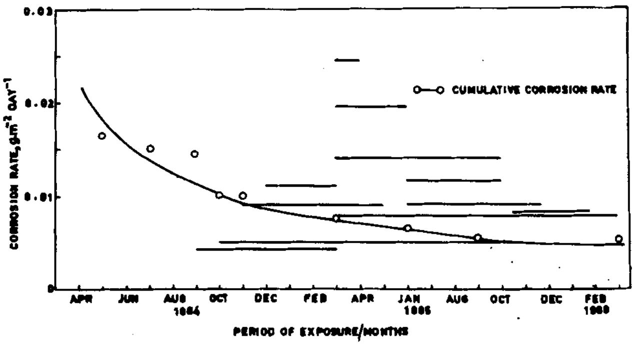

Fig 4 : Corrosion rate vs period of exposure for aluminium alloy 3004 exposed in open atmosphere

darkening of its bright surface. As the duration extended, numerous white spots nucleated on its surface. Pitting was not observed for up to 6 months of exposure. The "derusted" panels showed initiation of pitting after one year of exposure but its depth and number were low. Maximum rate was experienced during the period March - June 1985 and minimum rate was recorded during the period October 1985 - January 1986. The variation of corrosion rates is in conformity with the salinity values that prevailed during the periods. The half-yearly rates were almost average of the two periods covered. The half-yearly rate covering the fourth quarter of 1984 and first quarter of 1985 showed the lowest value due to the lower salinity value combined with washing by heavy rain [3]. The annual corrosion rate was in between the two half-yearly rates, and was near about the lower rate. This supports the view that protection is offered by the corrosion product formed on the panels. The cumulative corrosion rate of aluminium alloy 3004 also decreased exponentially, but not as fast as in case of copper and its alloy. The salinity of the site was usually higher and the humidity was always higher than 70% RH. This combination might have favoured the formation of an electrolyte containing $AlCl_3$ [4]. Al_2O_3 is a well-established passivating film on aluminium and its alloy, and it was expected that the rate should fall at a faster rate with duration of exposure. But this was not observed in the present study due to the formation of $AlCl_3$, further assisted by the alloying elements like Mg etc, which have a more anodic galvanic potential than aluminium.

Table-II shows the corrosion rate of the metal by 2 years exposure in comparison with a few other studies. The ratios of monthly maximum rate

Table II : Corrosion rate, g/m²/day

Metal	Present study 2 years	India [5] 2 years	Sweden [2] 2 years	Panama [6] 1 year
Copper	—	0.127	0.00245	0.10130
Brass	0.050	0.0585	0.00200	0.03014
5% Phosphor bronze	0.150	—	0.00395	0.12050
Aluminium (Commercial pure)	—	0.00698	—	0.00274
3004 Al alloy	0.004	—	—	—

to the rate by the two years of exposures were the same [5] for brass and phosphor bronze, but their absolute values differed by three times. The lower corrosion rates of all the metals even for one year of exposure site at Panama [6] was less than the corrosion rates determined from the present study by 2 years of exposure. The exposure site at Panama was situated about 2 km away from the sea and the salinity value should be expected to be less than at the present site and hence lower corrosion rate. The same explanation holds good for the exposure at Sweden [2] The present corrosion rates are comparable with those reported earlier [5] from Mandapam marine atmosphere, a location which is a kilometer away towards west from the present yard.

CONCLUSIONS

The more corrosive environment prevailing at the exposure yard of CECRI Corrosion Testing Station, Mandapam Camp can be used for testing compatibility to corrosion of the new materials developed. Brass showed a lower corrosion rate compared with copper, while phosphor bronze was found to be corroding faster than copper. But all of them indicated the protective nature of products formed. Surface modification to produce more impermeable corrosion product layer may be advisable for statinary structures and machines of copper and its alloy, where mechanical damage of the initially formed film does not take place. Aluminium and its alloys generally corrode at low rates, but in such an aggressive environment as Mandapam where considerable chloride ions are present, the benefit of a passivating film cannot be enjoyed.

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