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Atmospheric Corrosion Study of Metals in an Industrial Environment

R.T. VASHI† and H.K. KADIYA*
Department Chemistry, C.U. Shah Science College, Ashram Road, Ahmedabad-380 014, India
E-mail: vashirajendra@yahoo.co.in; hitesh_1330@yahoo.co.in

Corrosion rate of mild-steel (MS), zinc and aluminum as well as the sulphation rate was determined during 2005-2006 under outdoor exposure in an industrial environment at Vapi (Dist. Valsad) situated in South Gujarat, India. Monthly corrosion rate vary from 650 to 2014, 54 to 160 and 1.9 to 27.5 mg/dm^2 correspond to mild-steel, zinc and aluminium respectively, whereas the yearly corrosion rate vary from 9109 to 23495, 211 to 890 and 18.9 to 58.0 mg/dm^2 for mild-steel, zinc and aluminium respectively. Monthly corrosion rate was found in the decreasing order : mild steel > zinc > aluminium. Corrosion rate of these three metals was found more in rainy seasons than the rate of winter and summer season. There is a considerable loss of corrosion rate during exposure for one year of mild steel. Monthly corrosion rate of mild steel indicate a close correlationship with rainfall (r = 0.81), number of rainy days (r = 0.98) and satisfactory correlation with sulphation rate (r = 0.43). No correlation appeared to exist between temperature and corrosion rate of mild-steel, zinc and aluminium. The X-ray diffraction analysis of mild-steel corrosion product was also performed.

Key Words: Corrosion, Industrial environment, Mild-steel, Zinc and Aluminum.

INTRODUCTION

Atmospheric corrosion is a very important practical process that causes deterioration of structures, machines and materials placed at external environments[1,2]. It constitutes a relatively complicated electrochemical process that consists of a metal and its corrosion products, an electrolyte (a thin wet film on surface) and the atmosphere (more or less polluted). An industrial atmosphere is characterized by pollution composed mainly of sulphur compounds and nitrogen oxides. Sulphur dioxides from burning coal or other fossil fuel is picked up by moisture on dust particles as sulfurous acid.

In developed countries, the national annual cost of corrosion varies 1.0 to 3.5 % of the Gross National Product (GNP)[3]. Singh *et al.*[4] reported corrosion rate of steel exposed for 2 years at different locations of India found that, Chennai (industrial)

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†Department of Chemistry, Navyug Science College, Surat-395 009, India.

19.0 µm/y, Jamshedpur (industrial) 12.9 µm/y. Larrabee and Ellis[5] reported the yearly corrosion rate of steel plate (4″ × 6″ size) exposed in various atmospheres at different places of North America as follows: 6.52 mil/yr at New York (industrial atmosphere) and 3.30 mil/yr at Kearny (industrial atmosphere). Schikorr[6] exposed pure zinc plate for one year in various atmospheres and measured a corrosion rate as follows: 0.73 mil/yr at Bitterfeld and 0.19 to 0.24 mil/yr at Hamburg. Mattson[7] reported the corrosion rate of aluminium in the range of 1 to 3 $gm^{-2}y^{-1}$ in industrial atmosphere. In India, data regarding the relative corrosivity of atmospheres at Baroda[8] (industrial), Calcutta[9] (industrial), Surat[10] (industrial) and Ankleshwar[11] (industrial) are available.

EXPERIMENTAL

Test plates of mild steel, zinc and aluminium have the following chemical composition: (a) Mild-steel: C (0.038 %), Mn (0.265 %), S (0.015 %), Cr (0.021 %), Mn (0.006 %), Al (0.033 %), Ni (0.0115 %) and rest is Fe. (b) Zinc: 99.39 % purity, Pb (0.03 % max.), Cd (0.02 % max.), Fe (0.01 % max.). (c) Aluminum: 99.09 % purity and Si (0.53 %).

Test plates are individually mounted on a wooden rack. Special care should be taken that they were electrically insulated from surrounding metallic stand. The frame was placed in parallel outdoor fully exposed condition on the ground level making an angle of 45º towards the horizontal plane. Two types of time duration *viz*., monthly and yearly were considered for calculation of corrosion rate with time. All tests were carried out in duplicate and mean of the two values were taken. After exposure period test plates were wrapped in plastic bags and brought to the laboratory for cleaning. Different cleaning solutions are used to clean different metals. Hudson used Clark's solution[12] to remove rust from mild-steel made by 2 % Sb_2O_3, 5 % $SnCl_2$ in concentrated HCl (100 mL) at room temperature with constant stirring about 15-20 min. Zinc plates are derusted by 10 % CrO_3 and about 0.2 g $BaCO_3$ in distilled water (100 mL) at 25 °C for *ca.* 2 min[13]. Corrosion products on aluminum plates were removed by using the solution of concentrated HNO_3 containing chromic acid, 50 mg/L at a room temperature for *ca.* 10 min[14].

Control specimen was used to determine the loss of metal in a cleaning solution and the final figures of the loss in weight of exposed specimens were corrected accordingly.

Sulphur dioxide is considered as a major air pollutant causing the corrosion of most metals. The lead peroxide method used for monitoring SO_2 content in air[15]. Essentially, the technique depends upon the measurement of sulphation caused by gaseous SO_2 on an exposed lead peroxide paste. Lead dioxide in paste form was painted as a thin layer on a gauze cylinder (candle method) and allowed to dry. This PbO_2 reacts with SO_2 of air to form $PbSO_4$. After exposure, the lead peroxide layer was removed and the sulphate content was determined by a gravimetric method. These candles were exposed at the ground level on a rack with the panels.

RESULTS AND DISCUSSION

Meteorological and pollution data: The average maximum and minimum temperature was noted as 306 and 290 K corresponds to the year 2005 and 2006, respectively. There is a considerable variation in temperature during all months. The data of rainfall (in mm) and number of rainy days of the year 2006 are mentioned in Fig. 1. Relative humidity (minimum, maximum and mean) in percentage is shown in Fig. 2.

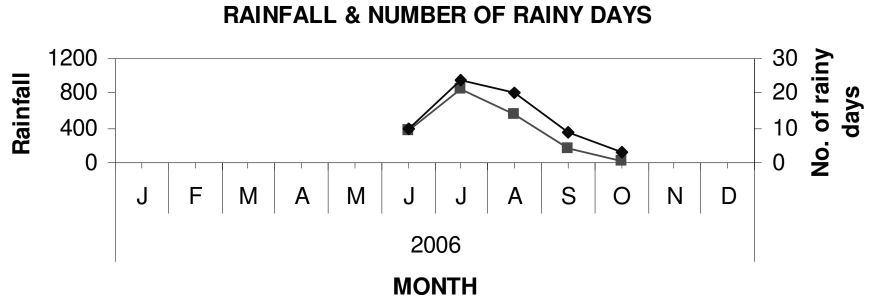

Fig. 1. Rainfall (mm) and number of rainy days at industrial area

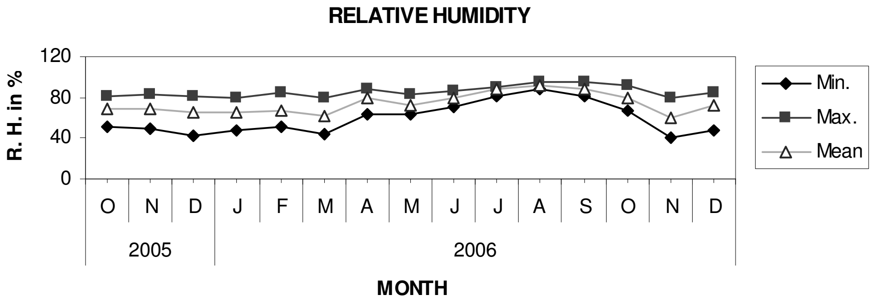

Fig. 2. Relative humidity (%) at industrial area

Sulphation rate (in mg SO_3/dm^2/month) of the study area is shown in Fig. 3. The prominent direction of wind is South-West (SW) during summer and monsoon season, with comparatively higher speed (9.0 km/h). A sulphation rate was measured at Vapi industrial environment, shows an appreciable value ranging from 13.6 to 46.0 mg SO_3/dm^2/month as shown in Fig. 3. Vashi and Patel[10] also measured a sulphation rate ranging from 28 to 65 mg SO_3/dm^2/month at Surat. Sulphation rate at a Liesegang[16] shows a value of 1.25-2.50 mg/dm^2/day and 30 to 90 mg/dm^2/month at Ankleshwar[11].

Mild-steel: The corrosion suffered by mild-steel was mainly of a general type. Approximately 2.2 mm thick corrosion product was formed on panels of 12 months exposure.

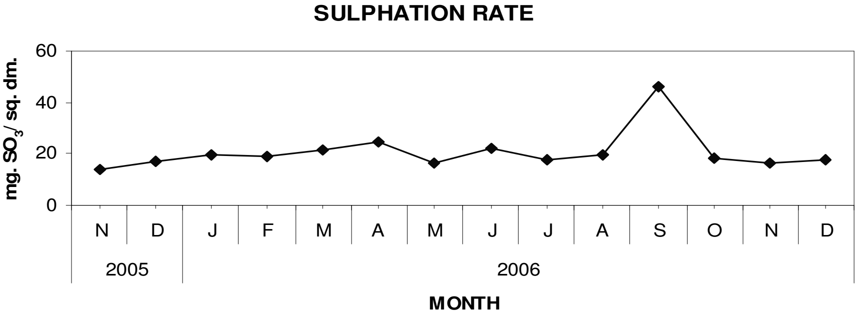

Fig. 3. Sulphation rate (mg. SO_3/dm^2/month) at industrial area

Corrosion rate of mild-steel varied from month to month and from season to season. Monthly corrosion rate of mild-steel was found in the range of 650 to 2014 mg/dm^2/month. These values are higher than that measured at 335 to 2200 mg/dm^2 at Surat[10] and 356 to 1625 mg/dm^2/month at Ankleshwar[11]. The yearly corrosion rate was found in the range of 9109 to 23495 mg/dm^2 shown in Fig. 4. These values are higher than the value of Surat[10] (11500 to 20076 mg/dm^2) and Ankleshwar[11] (13109 to 14925 mg/dm^2).

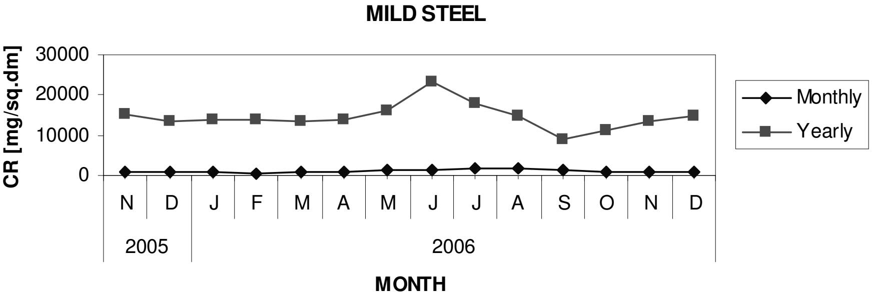

Fig. 4. Monthly and yearly corrosion rate of mild steel at industrial area

Monthly corrosion rate of mild-steel indicates a close correlation with rainfall ($r = 0.81$) and a number of rainy days ($r = 0.98$). Monthly corrosion rate of mild-steel indicates a satisfactory correlation with sulphation rate ($r = 0.43$). Monthly corrosion rate of mild-steel has a weak correlation with average relative humidity ($r = 0.20$). No correlation appeared to exist between temperature and corrosion rate of mild-steel.

Corrosion rate of mild-steel in rainy months is 3 to 4 times higher compared to the values obtained in winter months and the summer months. Panels exposed in winter months (November to February) indicate lower initial corrosion loss than the panels exposed to rainy months (June to September). This suggests that a protective film is formed on metal surface which can resist attack during subsequent exposure. Whereas higher corrosion rate in rainy months are attributed to the corrosion product which is washed regularly by rain keeping fresh metal surface exposed to further corrosion. Lower corrosion rate in summer months (March to May) are due to the removal of gaseous and particulate pollutants from the atmosphere by higher wind velocity.

The X-ray diffraction analysis data of mild-steel corrosion product (rust) of 12 months exposure period at industrial station indicates 8 peaks. The phases present in corrosion product in the industrial sites are iron silicon ($Fe_{0.42}$ $Si_{2.67}$).

Zinc: The corrosion suffered by a zinc plate is of the general type (uniform attack). Corrosion rate of zinc varied from month to month. Monthly corrosion rate of zinc varied from 54 to 160 mg/dm^2. This value is higher than the values obtained at Surat[10] (20 to 119 mg/dm^2), Ankeshwar[11] (67 to 167 mg/dm^2). Yearly corrosion rate of zinc at Vapi industrial station was varied from 211 to 890 mg/dm^2 (Fig. 5). This value is higher than the values obtained at Surat[10] (173 to 268 mg/dm^2) and Ankleshwar[11] (285 to 415 mg/dm^2). Corrosion rate for zinc plate in rainy months (459 mg/dm^2) was double compared to the values obtained in winter months (238 mg/dm^2).

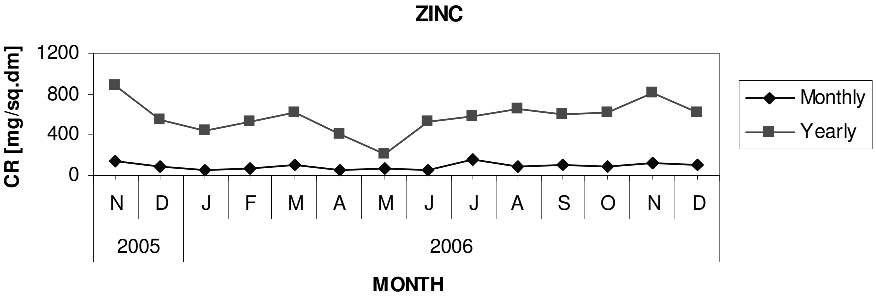

Fig. 5. Monthly and yearly corrosion rate of zinc at industrial area

Monthly corrosion rate of zinc indicates a satisfactory correlation with rainfall (r = 0.62) and with the number of rainy days (r = 0.56). Monthly corrosion rate of mild-steel has a weak correlation with average relative humidity (r = 0.20). No correlation appeared to exist between temperature and corrosion rate of zinc.

Aluminum: No significant attack was observed on aluminum panels. The corrosion rate of aluminum was found very low compared to mild-steel and zinc. Monthly corrosion rate for aluminum was found in the range of 1.9 to 27.5 mg/dm^2. Monthly corrosion rates of aluminum of various places are represented as follows: 3 to 15 mg/dm^2 at Surat[10] and 4 to 30 mg/dm^2 at Ankleshwar[11]. Yearly corrosion rate of aluminium was found in the range of 18.9 to 58.0 mg/dm^2 (Fig. 6). This yearly corrosion rate at Vapi is less influence by the initial condition of exposure which is in agreement with the result of Surat[10] (55 to 131 mg/dm^2) and Ankleshwar[11] (65 to 126 mg/dm^2). Corrosion rate of aluminum in rainy months (61.6 mg/dm^2) was 3 to 4 times higher compared to the corrosion rate of winter months (15.5 mg/dm^2) and summer months (21.5 mg/dm^2).

Low corrosion rate of aluminum in outdoor exposure is attributed with the formation of a more protective oxide film on the metal surface which might have offered protection to the metal from reacting with the surrounding environment. The results are agree well with a previous report that aluminum is highly resistant to normal outdoor exposure condition and that the rate of attack greatly decrease with increase in the time of exposure due to a self-stopping action[17].

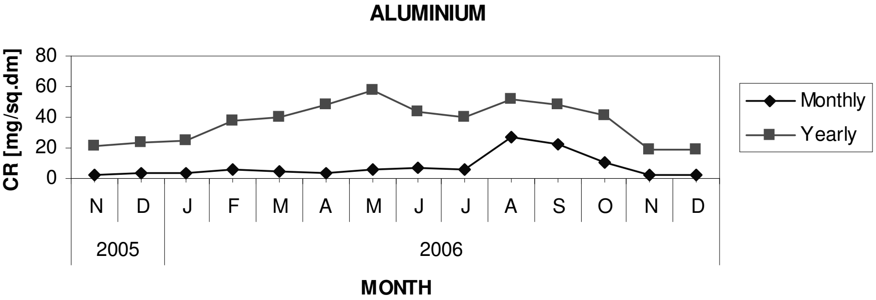

Fig. 6. Monthly and yearly corrosion rate of aluminium at industrial area

Conclusion

- Monthly corrosion rate of mild-steel was 5 to 25 times higher compared to zinc. Similar results obtained at different cities are as follows: Surat[10] (12 to 26 times), Ankleshwar[11] (4 to 14 times). The yearly corrosion rate of mild-steel was 17 to 77 times higher than the corrosion rate of zinc.
- Monthly corrosion rate of mild-steel of industrial station was 68 to 376 times higher compared to aluminium. Similar results obtained at Surat[10] (111 to 300 times) and Ankleshwar[11] (33 to 180 times); whereas yearly corrosion rate of mild-steel was 186 to 784 times higher compared to aluminium.
- Monthly corrosion rate of zinc of industrial station was 3 to 63 times higher compared to aluminium. Similar results obtained at Surat[10] (7 to 15 times) and Ankleshwar[11] (6 to 22 times); whereas yearly corrosion rate of zinc was 4 to 42 times higher compared to aluminium.

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