Atmospheric Corrosivity Survey of India

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This article reports the results of an atmospheric corrosivity survey conducted in India and summarizes similar studies in other countries. In India, mild steel, galvanized iron, zinc, and aluminum specimens were exposed for one year at 37 exposure stations and their weight losses were measured. The data collected from these exposure stations were analyzed and presented in an updated corrosion map of India. Corrosion was found to be spot-specific and not region-specific.

Atmospheric corrosion accounts for many failures in terms of cost and tonnage. The aggressiveness of an atmospheric environment can be assessed by measuring the climatic and pollution factors, or by determining the corrosion rates of exposed metals and coatings.

Corrosivity of the atmosphere in a particular area is important in the selection of materials and suitable protective coatings. A corrosion map is useful, as it gives a general or broad indication of the corrosivity of the atmosphere in different locations in the country.

It has been customary to classify environments as rural, urban, industrial, marine, or combinations of these. Rural environments generally are the least corrosive and normally do not contain chemical pollutants, but do contain organic and inorganic particulates. The urban environment is similar to the rural type, in that there is little industrial activity. Industrial atmospheres are associated with heavy industrial manufacturing facilities and can contain concentrations of sulfur dioxide (SO_2), chlorides, phosphates, and nitrates. Fine wind-swept chloride particles deposited on surfaces characterize the marine atmosphere.

World Status

Much work has been undertaken on the atmospheric corrosion behavior of different materials over several decades. Maps have been produced for a number of geographic regions, illustrating macroscopic variations in corrosion. The availability of atmospheric corrosivity maps can help facilitate materials selection and determine appropriate protection systems and maintenance intervals.

The following summaries highlight corrosion mapping activities in various countries.

SPAIN

The University of Barcelona has embarked upon an ambitious program to study a ~31,666-km^2 region of the northeast area of the Iberian Peninsula.[1] This study had two important conclusions: a) carbon steel (CS) is the least sensitive material to pollution, while the effects of pollution are quite significant for metals like stainless steel and aluminum, and b) the effect of pollution on the corrosion behavior of materials as a function of geographical area has assumed a great practical importance. It was also possible to establish the effect of a potential pollution eliminator.

UNITED KINGDOM

In the United Kingdom, there has been a paucity of data on contemporary rates of corrosion.[2] As a result, it was not possible to determine whether corrosion rates responded to environmental changes, particularly a large reduction in SO_2 level.

UNITED STATES

LaQue Centre for Corrosion Technology is a pioneering institution involved in carrying out atmospheric corrosion studies. This center ranked the corrosivity of a number of sites in Canada as well as in the United States using the mass loss technique.[3] The data indicated that short-term mass loss data could exhibit wide variations because of uncontrolled environmental factors in natural atmospheric environments and seasonal effects associated with time of exposure initiation. Thus, longer exposure (one to two years) is intended to average out the influence of large fluctuations in short-term (one-month) environmental variables.

SINGAPORE

The corrosion of mild steel was studied at two sites in Singapore (inland and on a raft in the sea) for three periods and with two surface conditions.[4] Corrosion of mild steel was significantly faster on the raft than inland. The long-term corrosion rates of specimens exposed to the inland marine environment and on the raft were found to be 0.016 mm/y for a two-year exposure and 0.659 mm/y for ~0.6 years' exposure, respectively.

NEW ZEALAND

New Zealand's climate is warm and humid, with prevailing westerly winds depositing large amounts of sea salt far inland, a condition thought to pose a severe atmospheric corrosion hazard.[5] Steel, aluminum, and galvanized steel were exposed for one year at 168 sites located throughout the country. One-year corrosion rates ranged between 18 to 4,800 g. m^{-2}/y for steel and 0.7 to 1,417 g. m^{-2}/y for galvanized steel. Results for aluminum were significantly greater than zero at a small number of severe marine sites only. A maximum corrosion rate of 2.6 g. m^{-2}/y was found. At one industrial site, a rate of 1.3 g. m^{-2}/y was recorded. A clear correspondence between corrosion rates and proximity to the coast is evident in these results, implying that atmospheric corrosion rates in New Zealand are related to levels of chloride deposition.

TABLE 1

SITE LOCATIONS AND TYPICAL DURABILITY FACTORS FOR GALVANIZED IRON, ZINC, AND ALUMINUM WITH RESPECT TO BARE MILD STEEL

No.	Test Site	Durability Factors		
		GI	Zn	Al
	Rural			
1	Aligarh	6	7	30
2	Bhopal	84	28	44
3	Bhubaneswar	16	30	33
4	Chandigarh	13	18	16
5	Dindigul	8.0	42	14,000
6	Karaikudi	62	6	61
7	Mahendragiri	4	2	3
8	Warangal	2	4	169
9	Salem	16	10	1,262
	Industrial			
10	Coimbatore	—	16	4
11	CECRI Unit, Kochi	14	36	503
12	Manali	25	5	82
13	Mettupalayam	—	43	33
14	Mumbai	19	26	27
15	Tirupur	—	180	6
16	Vishakapatnam	13	10	8
17	Kolkatta	13	18	98
	Marine			
18	Chennai	45	73	61
19	Cuddalore	12	23	44
20	Kakinada	—	—	—
21	Kanyakumari	6	7	5
22	Kayamkulam	6	14	84
23	Kochi	24	25	180
24	Mandapam Camp	9	9	156
25	Mangalore	16	79	21
26	Marumogao	2	22	41
27	NIO GOA	13	24	121
28	Nagapattinam	90	11	2,890
29	Padubidri	—	1	—
30	Pondicherry	—	18	—
31	Port Blair	2	2	10
32	Sriharikota	—	35	552
33	Tuticorin	3	2	4
	City Area			
34	Hyderabad	10	9	54
35	New Delhi	7	35	67
36	Pune	5	8	368
37	Surat	11	13	7

SOUTH AFRICA

South Africa is a country that experiences extreme climatic conditions with drought periods of seven to eight years being not uncommon.[6] Realistic data could be obtained only over a long exposure period of 10 years or more.

CHINA

Atmospheric exposures were made at seven sites in China over eight years.[7] The exposure included the most common CS and low-alloying weathering steels. The testing sites covered typical conditions of temperate, subtropical, industrial, marine, rural, humid, and dry environments.

GERMANY

Results of tests conducted from 1989 to 1994 showed a significant decrease of corrosivity from earlier data because of a lower deposition rate of the corrosion pollutant SO_2.[8] This positive development can be explained by an improvement of the atmosphere because of changes to the industrial structure, as well as by active measures of environmental protection.

FIGURE 1

Atmospheric exposure stand at Chennai Naval Base site.

SWEDEN AND CZECHOSLOVAKIA

The Swedish Corrosion Institute and the State Research Institute for Protection of Materials in Czechoslovakia have collected data from more than eight years of exposure at 11 test sites.[9] The studies revealed the decisive influence of SO_2 pollution and of chlorides on the corrosion attack of CS, zinc, copper, and aluminum.

AUSTRALIA

In Australia, the Division of Building, Construction and Engineering has been engaged in atmospheric corrosion mapping.[10] The corrosivity mapping over five years indicates that ~\$0.6 million/year could be immediately saved by improved material selection and better maintenance planning.

VIETNAM

Vietnam is situated in a tropical zone and corrosion of metals has been a major problem. Although air pollution by industrial gases is negligible, atmospheric salinity together with climatic factors accelerate the corrosion of metals.

INDIA

It has been nearly 35 years since the first corrosion map of India was made.[11-12] Since that time, many environmental changes have occurred because of industrialization, population growth, and the enormous vehicle population. The earlier maps were based on the corrosion/pollution data collected over a period of five years from 1963 to 1968 at exposure stations located in different parts of the country.

The Central Electrochemical Research Institute (CECRI), Karaikudi, has initiated a long-awaited exercise to prepare a new corrosion map of India by collecting data on atmospheric pollution and the corrosion rate of mild steel, zinc, galvanized iron, and aluminum under a wide variety of environmental conditions at 37 exposure sites. The data collected from these field stations were analyzed and presented in an updated 2004 corrosion map of India for mild steel. The maximum and minimum corrosion rates for other metals and the durability factors of these metals with respect to mild steel were also reported.

Experimental Procedures

Thirty-seven field exposure sites (Table 1) were selected in different locations. The exposure stands were fabricated as per IS 5555-1970[13] (Figure 1). Commercially available metals such as mild steel, zinc, galvanized iron, and aluminum were used for this study. Specimens measuring 100 by 150 mm were prepared and cleaned of scale and other products by pickling. They were polished and weighed before exposure. The metal specimens were then positioned on the exposure stands at an angle of 45 degrees from the horizontal. One set of exposed specimens was removed after one year. The specimens were cleaned as per IS 5555-1970, dried, and reweighed. The difference between final weight and initial weight gave the loss of metal for the one-year period.

Atmospheric pollutant levels of SO_2 and salinity were determined continuously in some exposure stations. SO_2 was estimated as sulfate by the lead dioxide (PbO_2) candle absorption method and salinity was determined via humid candle methodology as described in IS 5555-1970. The climatic parameters, such as temperature, rainfall, and relative humidity, were obtained from the meteorological observatory stations.

Results and Discussion

Data were collected from 1993 to 2003 at the 37 exposure sites.

MILD STEEL

The data collected from these field stations were analyzed and presented in the form of an updated 2004 corrosion map of India for mild steel (Figure 2). In this updated map, annual corrosion rates for mild steel (mmpy) were designated in four ranges, each range being denoted by a color code. The highest range is denoted by a red circle and the lowest range by a green circle. The lowest range is less than the one-tenth of the highest range.

Out of 37 locations, only five fall in the highest range. Three locations are along the coast, one is on Port Blair Island, and one is slightly inland. Another interesting feature of this map is that the corrosion is spot-specific and not-region specific. For example, along the east and west coasts, different color spots are found, indicating that the corrosion ranges from mild to extremely severe.

Figure 3 shows a mild steel panel exposed at the Chennai Naval Base site over an exposure period of eight months. Powdery and flaky rust products can be seen. The thickness was reduced from 2.5 to 0.5 mm.

GALVANIZED IRON, ZINC, AND ALUMINIUM

Corrosion rates of galvanized iron, zinc, and aluminum were determined at 37 exposure stations. Table 2 gives the maximum and minimum rates.

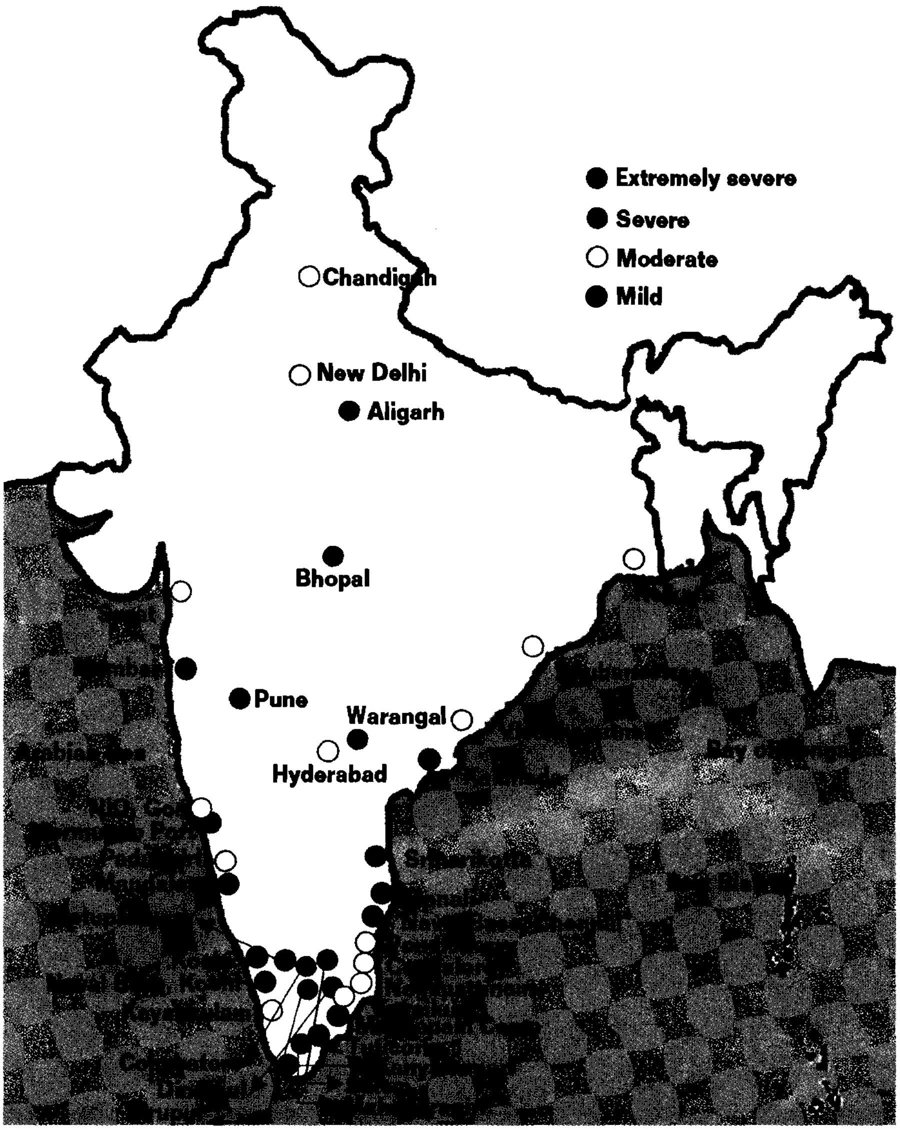
Significance of Corrosion Data

The study revealed the following findings:

- There was a wide variation in the corrosion rate of more than one order of magnitude.
- A 0.01-mmpy corrosivity area may need a normal protective scheme.
- 1.6-mmpy corrosivity areas may need the most effective protective scheme.

The data collected from the 37 test sites indicate that the corrosion rate of zinc is also spot-specific and not region-specific. The only difference is that the highest and lowest corrosion rates of zinc are lower than those of mild steel. The corrosion rates of galvanized iron are almost similar to those of zinc. Interestingly, in the case of galvanized iron, the number of extremely severe spots is fewer than for zinc. For aluminum, the corrosion may vary widely from spot to spot; therefore, the performance of aluminum is more location-specific than that for mild steel, zinc, and galvanized iron.

FIGURE 2



Updated 2004 atmospheric corrosion map of India for mild steel.

DURABILITY FACTORS

The durability factor is the ratio between the corrosion rate of mild steel and that of the nonferrous metal exposed in a particular spot. Table 1 gives the durability data. This is an important parameter that will be of help to designers in the selection of durable engineering materials for a particular spot.

Durability data clearly indicate that nonferrous metals such as galvanized iron, zinc, and aluminum have better durability factors relative to bare mild steel, although these factors vary from spot to spot. The durability factor varies from 1 to 90, 2 to 180, and 2 to above 2,890 for galvanized iron, zinc, and aluminum, respectively. These durability data were determined from one-year corrosion data. The generation of long-term data will yield a realistic picture on relative durability.

Long-term exposure of aluminum may sometimes lead to localized corrosion. Durability and cost factors taken together, however, indicate that aluminum has effective cost benefits. At certain spots, galvanized iron may prove to be a cost-effective material.

TABLE 2

SALIENT FEATURES OF THE CORROSION RATE OF METALS

Engineering Materials	Corrosion Rate (mmpy) Highest	Lowest
Mild steel	1.6	0.01
GI	0.27	0.0001
Zn	0.22	0.0001
Al	0.04	0.000001

FIGURE 3

Mild steel panel exposed at Chennai Naval Base over a period of eight months.

Conclusions

Atmospheric corrosivity of mild steel, zinc, galvanized iron, and aluminum were measured at 37 exposure sites located throughout India. Data collected from these field sites were analyzed and presented in the form of an updated 2004 corrosivity map of India for mild steel (Figure 2). The interesting feature of this map is that the corrosion is spot-specific and not region-specific. Durability factors for the nonferrous metals indicate that galvanized iron, zinc, and aluminum have good durability relative to bare mild steel.

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