Corrosivity and durability maps of India

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THE ATMOSPHERIC corrosion behaviour of engineering materials such as mild steel, zinc, galvanized steel, and aluminium has been studied at 40 exposure stations in India, and corrosion data from the sites have been collected for over 11 years, from 1993-2004. The data collected from these sites have been analyzed and presented in the form of updated corrosion maps of India. In these maps, the annual corrosion rate for each particular material have been arranged in four ranges, which are colour coded. An interesting feature of the maps is that the corrosion is area-specific, and not region-specific.

The durability factor is defined as the ratio between the corrosion rate of mild steel and that of a non-ferrous metal exposed at a particular location. The durability data have been analyzed and are presented as durability maps of India. The data clearly indicate that non-ferrous metals, such as galvanized steel, zinc, and aluminium, have better corrosion resistance than bare mild steel. However, the factors vary from area to area. These data were calculated from one-year exposure studies. If the durability and the cost factors are taken together, it can be clearly seen that aluminium has an appreciable cost-benefit ratio; at certain locations, galvanized steel may also prove to be a cost-effective material.

WORLD-WIDE, studies have shown that the overall cost of corrosion amounts to at least 4-5% of the gross national product, and in that 20-25% of this cost could be avoided by using appropriate corrosion-control technology. Atmospheric corrosion is the major contributor to this cost. The aggressiveness of the atmospheric environment can be assessed by measuring the climatic and pollution factors, or by determining the corrosion rates of exposed metals and coatings. The loss due to corrosion is often compared with that of other calamities such as earthquake or cyclone; in fact, similar to earthquakes and cyclones, corrosion is a natural process, the only difference being that its impact is invariably indirect. In the case of earthquakes, mapping of seismic zones is already practiced; in the case of cyclones, also, weather prediction is available on a global level. Different countries are independently preparing their own corrosivity maps [1-11], confined to the regions of their interest.

The corrosivity of the atmosphere in a particular area or location is important to engineers and general users, helping them select materials and suitable protective coatings; it is unnecessary to point out that

Sl. No.	Exposure station	Temp. [°C]		Relative humidity [%]		Rainfall [mm]	Pollutants	
		Max.	Min.	Max.	Min.		SO_2 [mg/m².d]	Salinity [mg/m².d]
1	Aligarh	40	6	90	58	217	11	20
2	Bhavnagar	38	18	85	61	186		
3	Bhopal	40	10	94	52	501	traces	24
4	Bhubaneswar	38	16	92	55	336	8	21
5	Chandigarh	39	7	91	58	269	0	18
6	Naval Base Chennai *(note 1)*	39	20	88	59	355	18	486
7	Coimbatore	40	20	83	69	240	0.1	20
8	Cuddalore	35	21	90	64	702	0	63
9	Dindigal	37	21	82	52	64	8	15
10	Hyderabad	45	14	84	58	165		18
11	Jorhat	35	16	90	61	686	10	22
12	CECRI Unit, Kochi	32	22	95	50	580	31	50
13	Kakinada	38	17	88	63	320	0	121
14	Karaikudi	33	21	80	65	180	0	3 8
15	Kolkata	36	12	90	54	320	19	26
16	Kanyakumari	34	22	87	58	89	0	38
17	Kayamkulam	34	14	96	86	426	18	448
18	Lucknow	36	17	92	64	110		28
19	Mahendragiri	37	19	92	91	83	0	0
20	Manali	39	19	98	59	309	25	120
21	Mandapam camp	33	26	78	57	96	0	246
22	Mangalore	34	19	92	63	308	traces	110
23	Marumugao *(note 2)*	33	17	86	61	248	22	425
24	Mettupalayam	40	15	95	84	22	630	traces
25	Mumbai	33	19	89	58	945	14	48
26	Nagapattinam	34	22	80	61	750	0	29
27	Naval Base Kochi	32	23	99	54	592	31	79
28	New Delhi	40	6	98	56	184	.	
29	NIO Goa	31	16	89	63	248	0	0
30	Padubidri	33	18	93	65	310	9	124
31	Pondicherry	36	21	85	60	735	11	37
32	Port Blair	31	22	98	59	3028	0	356
33	Pune	38	12	86	64	167	12	34
34	Salem	38	22	85	60	68	0	45
35	Sriharikota	40	15	98	50	450	0	5000
36	Surat	42	14	92	54	310	8	22
37	Tirupur	37	20	98	86	214	1	20
38	Tuticorin	35	21	95	53	90	534	59
39	Visakhapatnam	38	18	95	61	327	13	23
40	Warangal	45	15	85	60	170		

Table 1. Average climatic and pollution parameters at the exposure stations.

Notes:

1 The Chennai naval base exposure station was about 150m from the Bay of Bengal coast, and situated near the port of Chennai. The port handles coal, crude oil, iron ore, and other industrial products, and therefore a lot of dust was deposited on the samples' surface.

2 The Mormugao exposure station was within the port area. A mixture of iron ore, carbon particles, and other dust particles was deposited on the exposed metal surface, the concentration of which found to be 480mg/m².day.

these data will be immensely useful to design engineers. The utility of the corrosion map is similar to that of other data, such as meteorological maps indicating rainfall and temperature, and soil maps depicting soil characteristics, etc., as it provides a general indication of the corrosivity of the atmosphere in different locations in a country.

Fig.1. Stand for atmospheric exposure.

Earlier corrosion map of India

It is almost 35 years since the first corrosion map of India was issued, and over the intervening years a lot of environmental changes have occurred, due to industrialization, population growth, and the enormous pollution caused by vehicles. It is therefore high time to update the corrosivity map. The earlier maps were based on the corrosion / pollution data collected over a period of five years from 1963-1968 at 26 exposures stations located in different parts of the country [12]. Even

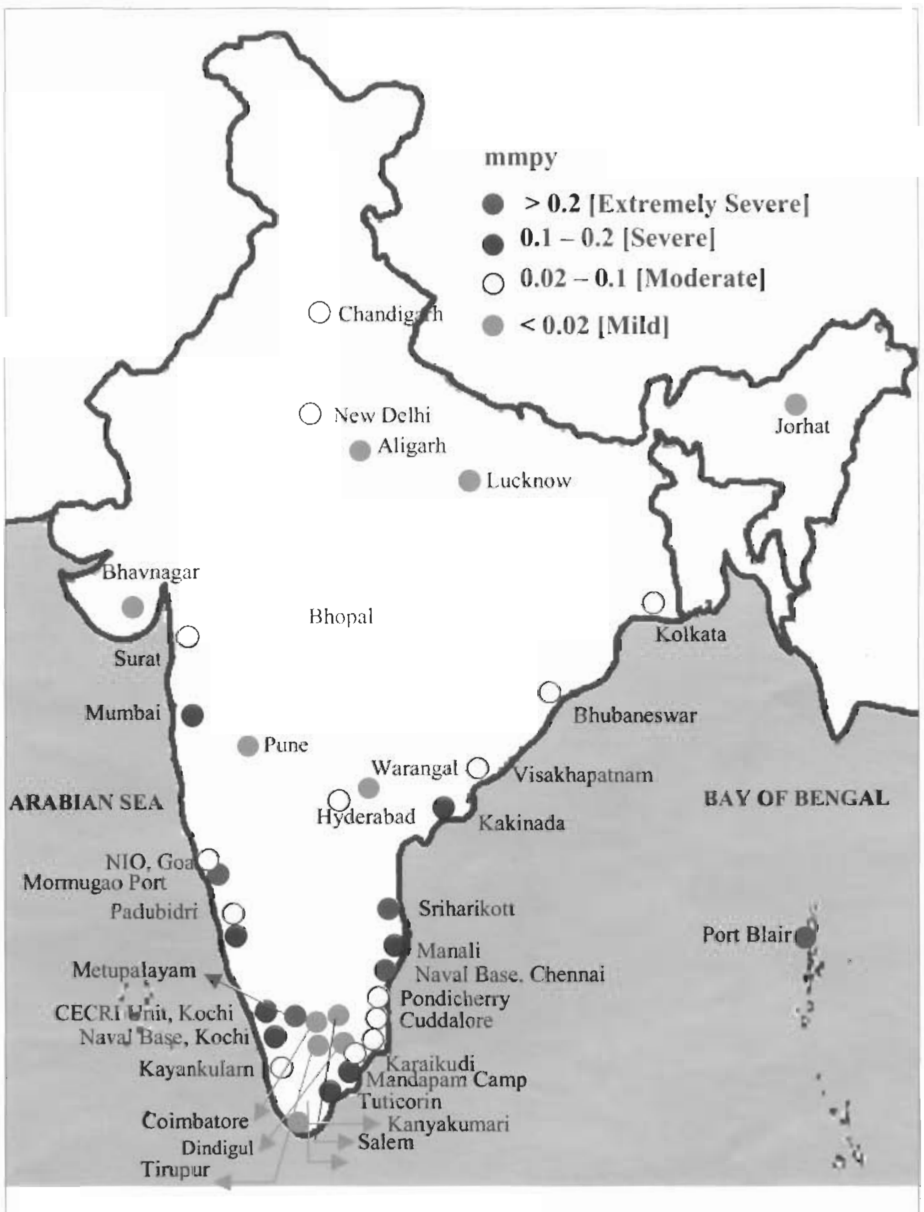

Fig.2. Updated corrosion map of India for mild steel, 2004.

at that time it was felt that number of stations were few in relation to the total area to be covered and the environmental conditions encountered.

The Central Electrochemical Research Institute (CECRI) has therefore initiated a long-awaited exercise to prepare a new corrosion map of India by collecting data on the atmospheric pollution and corrosion rate of some of the widely-used engineering materials, including mild steel, galvanized steel, zinc, and aluminium in various environmental conditions.

In this paper, the corrosion data collected from 40 exposure stations have been analyzed and presented in the form of updated corrosivity maps of India; the results are also interpreted in terms of durability factors.

Experimental details

The 40 atmospheric exposure stations were established throughout India. These stations cover a wide range of environmental conditions, ranging from industrial, marine, and rural to city areas. Atmospheric pollution levels of SO_2 and salinity were determined monthly over a period of one year in some exposure stations; the SO_2 content was estimated as sulphate by the lead peroxide candle-absorption method, and salinity was

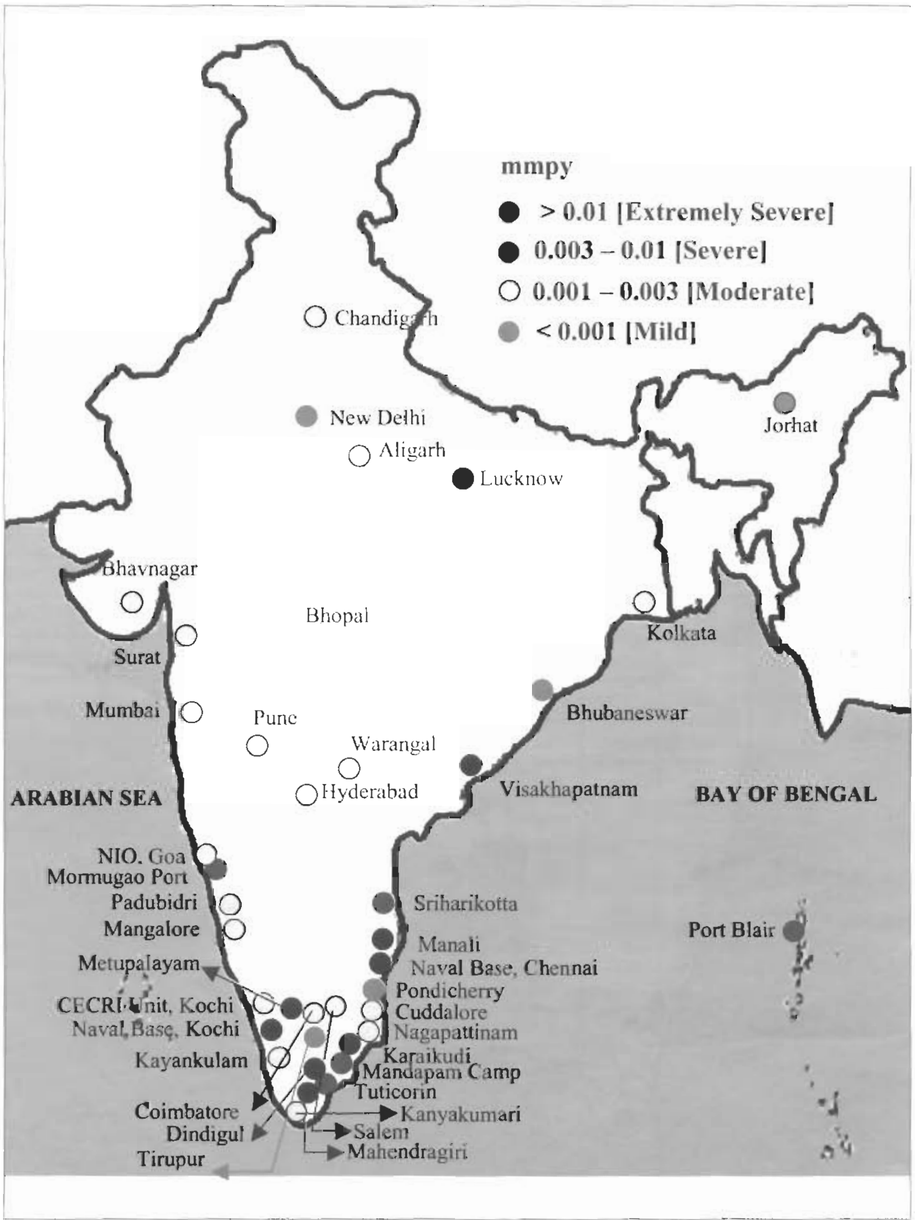

Fig.3. Updated corrosion map of India for zinc, 2004.

determined by the humid-candle methodology, as described in IS: 5555:1970. The average climatic parameters such as temperature, rainfall, and relative humidity were obtained from the respective meteorological observatory stations (Table 1).

The commercially-available metals used for the study were mild steel, galvanized steel (13 to 17-mm zinc coating on steel), zinc, and aluminium, and the metal specimens of size 100 x 150mm (thickness 2-4mm) were cut from the respective sheets. They were polished, degreased with trichloroethylene, and weighed before exposure. Then the specimens were exposed on the exposure stands at an angle of 45° from the horizontal as described in IS: 5555:1970 [Fig.1]. In order to determine the corrosion rate, one set of exposed specimens was removed after one year, and was cleaned in recommended cleaning solution as given in IS 5555:1970, dried, and reweighed. The corrosion rate was determined by ascertaining the loss of weight undergone by the test specimens during the first year of exposure.

Results and discussions

Preparation of updated corrosion maps

The corrosion maps have been drawn on the basis of the data collected over a period

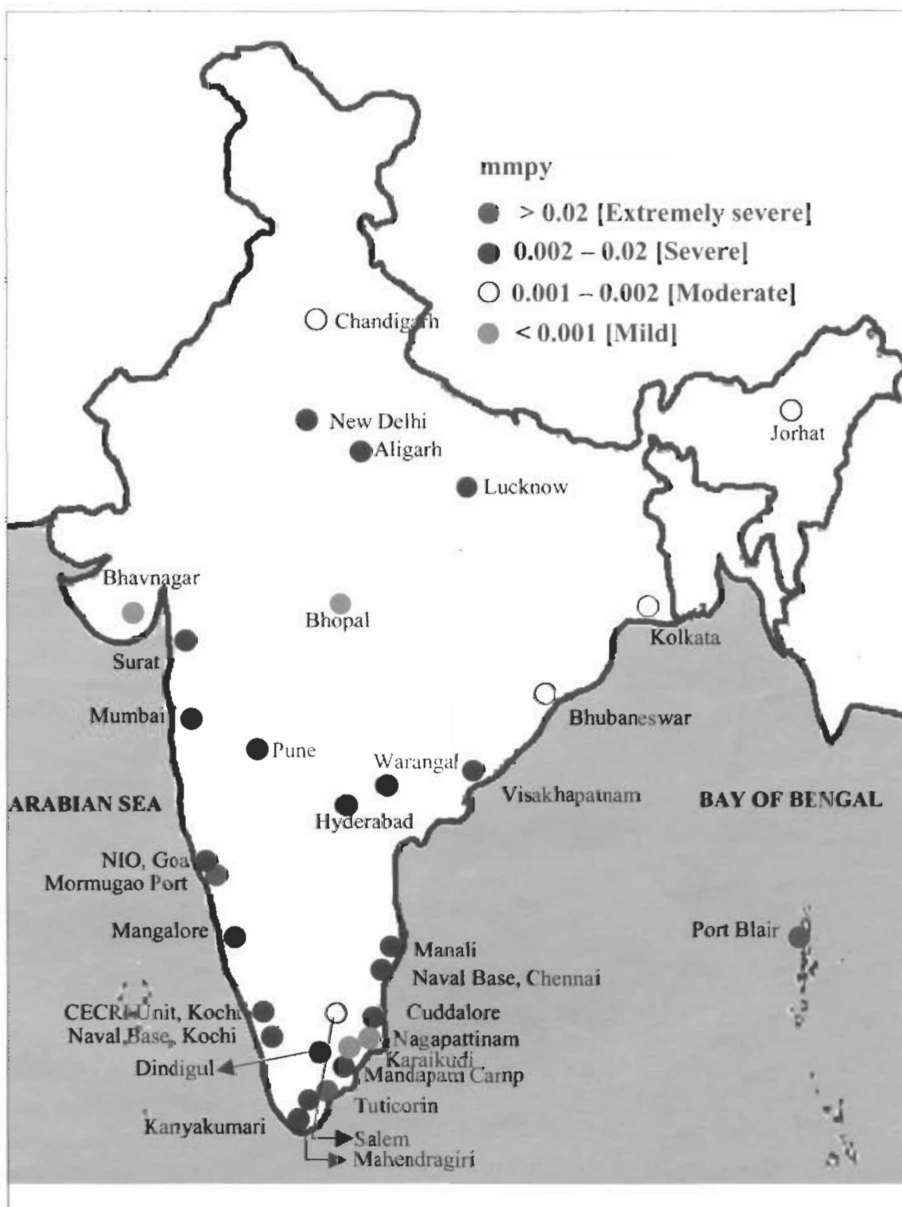

Fig.4. Updated corrosion map of India for galvanized steel, 2004.

of 11 years from 1993-2004, covering 40 field exposure stations. These maps at this stage must be considered as tentative. Tests at some more stations have been begun, and changes will be made to the maps as and when necessary. The results are shown in Figs 2 to 8.

General observations

The corrosion data collected from the field stations have been analyzed and presented in the form of updated corrosion maps of India. In these maps the annual corrosion rates for a particular material in mm/yr (mmpy) has been arranged in four ranges, each of which is denoted by a particular colour. The highest range is shown by a red circle, and the lowest range is denoted by a green circle; the lowest range is less than 10% of the highest range.

Interesting feature of these maps is that the corrosion is area specific and not region specific. For example, along the east as well as the west coasts, different corrosion rates could be observed, indicating that corrosion can be either in the lowest range or in the highest range even though the location is on the coastline. The corrosion rate results are given in Tables 2 and 3.

Significance of the data

It can be seen from Table 3 that there is a wide variation in corrosion rate, of more than one order of magnitude The areas

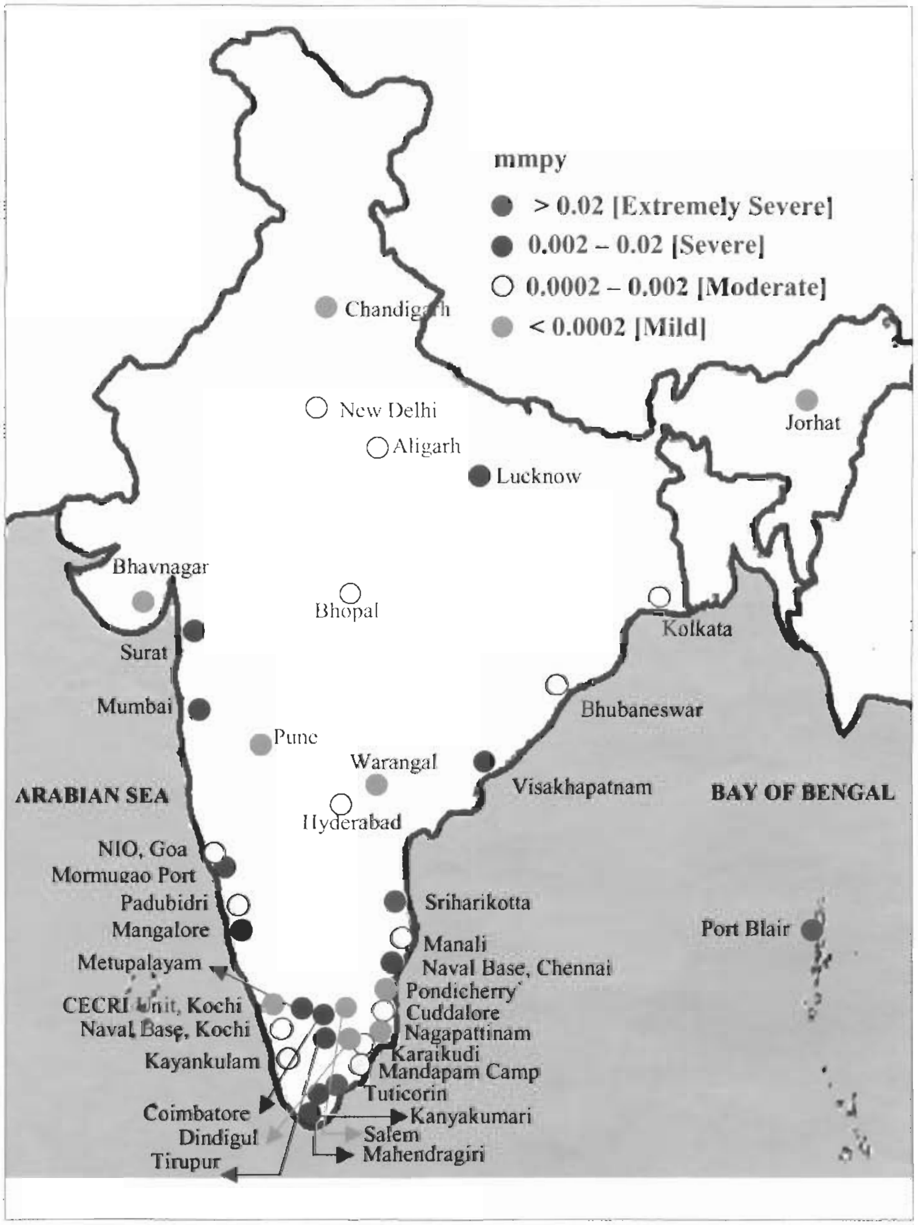

Fig.5. Updated corrosion map of India for aluminium, 2004.

Engineering materials	Corrosion rate (mmpy)		Durability factor	
	Highest	Lowest	Highest	Lowest
Mild steel	1.6	0.01	1	1
Zinc	0.22	0.0001	180	2
Galvanized iron	0.27	0.0001	89	1.4
Aluminium	0.04	0.000001	2890	2

Table 2. Salient features of the corrosion rate and durability factors of the metals tested.

with less than 0.01 mmpy corrosivity may need normal protective scheme, while the areas with greater than 1.6mmpy corrosivity may need most effective protective scheme.

Mild steel

Figure 2 shows the updated corrosion map of India for mild steel. Out of 40 locations, only five locations are in the highest range

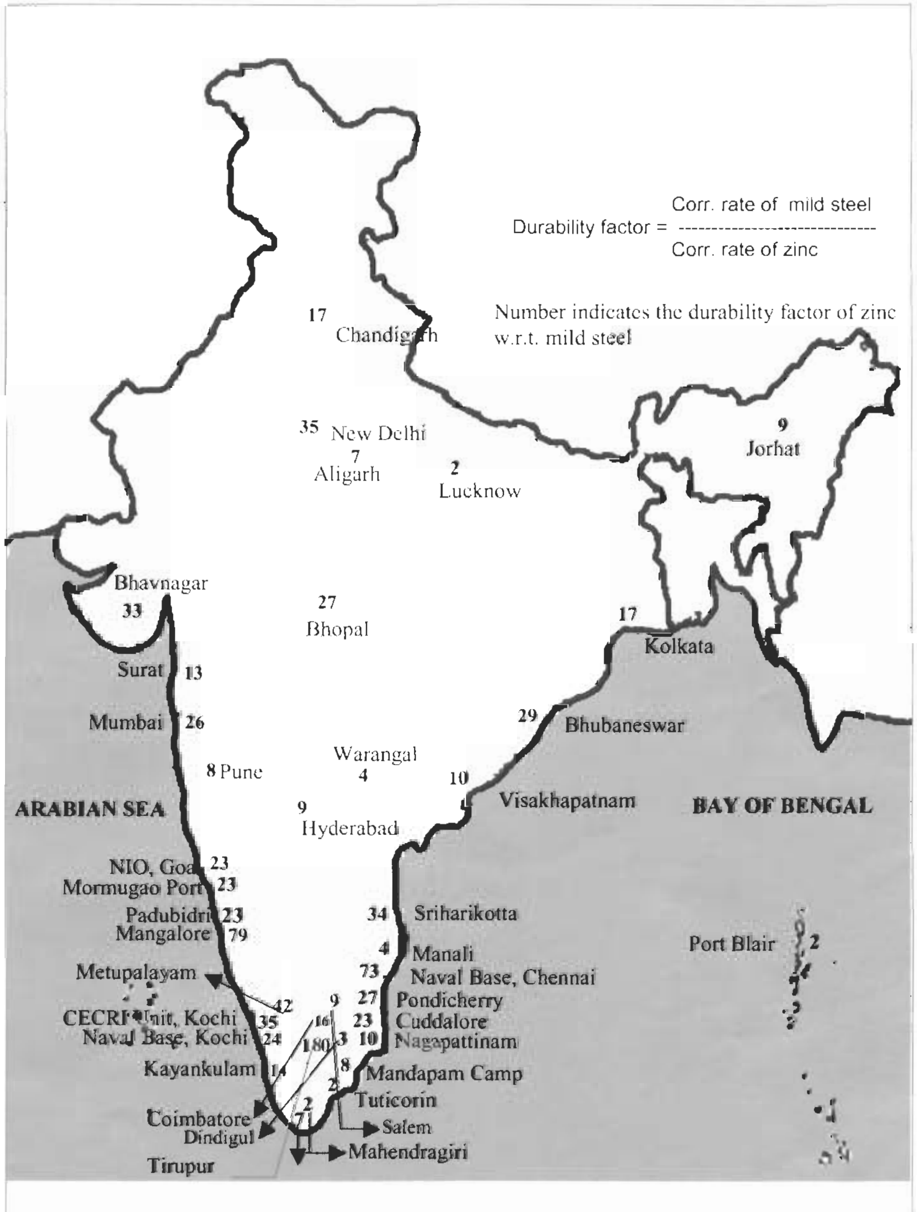

Fig.6. Durability map of India for zinc, 2004.

(extremely severe). Out of these five, three locations – Shriharikota, Chennai Naval Base, and Murmugao Port – are along the coast, and one is in the island of Port Blair. The fifth location –Mettupalayam's industrial area – is inland.

Based on the findings, Sriharikota, Chennai Naval base, Mormugao Port, Port Blair, and Mettupalayam are extremely corrosive. The high value of salinity, (5000, 486, 425, and 365mg/m^2.d at Sriharikota, Chennai Naval base, Mormugao Port, and Port Blair exposure stations, respectively), relative humidities above the critical value, heavy rainfall, and large variations between the maximum and minimum temperature are the main reasons for higher corrosion in the coastal region (Table 3). The Mettupalayam exposure station is situated 40km away from Coimbatore, near the hill area. Viscose and many chemical industries are located in this site, and the SO_2 content in the atmosphere is the main important industrial pollutant, the value of which was found to be in the range of 450-630mg/m^2.d. The salinity was found to be trace, the relative humidity was more than 90%, and the minimum-maximum temperature range was 15-40°C; the difference in temperature favoured higher condensation.

The combinations of a high SO_2 content with high relative humidity accelerated the corrosion of mild steel at this site.

Fig.7. Durability map of India for galvanized iron, 2004.

Zinc

The corrosion map for zinc is shown in Fig.3. It can be seen that out of 40 locations, only six are in the highest range. Out of these six, four are on the east coast, one is on the west coast, and one is on Port Blair. In this case, also, the corrosion rate is area specific and not region specific. The only difference is that in the case of zinc, the highest and lowest corrosion range is very much lower than that of mild steel.

Galvanized steel

The corrosivity map for galvanized steel is shown in Fig.4, from which it can be seen that only three marine locations – Mormugao, Tuticorin, and Port Blair – show the highest range, while the other locations show the lowest range. The corrosion rates are almost similar to those of zinc, but there is a change in the highest corrosion range. Interestingly, in the case of galvanized steel, the number of high corrosion areas is smaller.

Aluminium

Figure 5 shows the corrosion map for aluminium, from which it can be seen that out of the 40 locations, only three marine locations show the highest range. Out of these three, two sites are located on the east coast, and one is in Port Blair. The interesting feature for aluminium is that

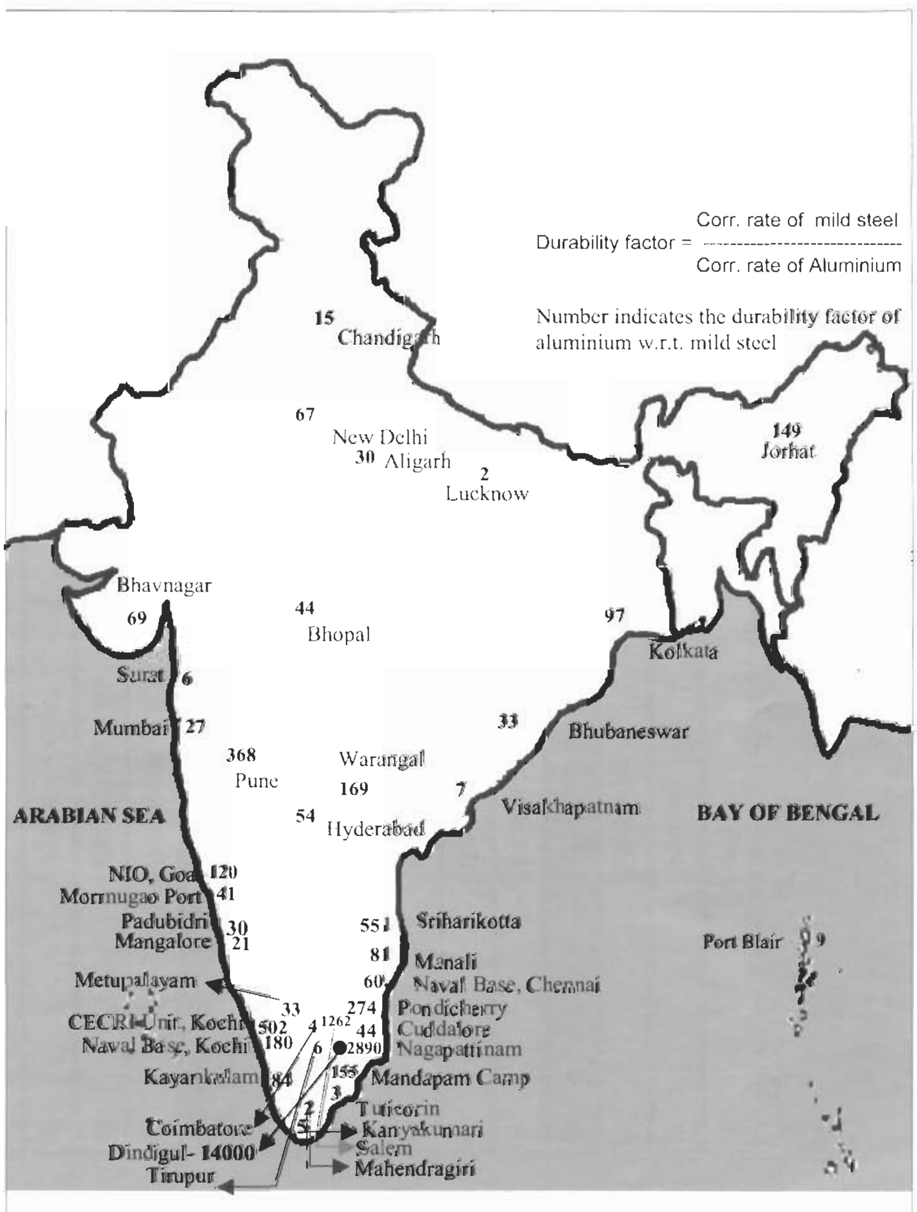

Fig.8. Durability map of India for aluminium, 2004.

No.	Station	Corrosion rate (mmpy)			
		MS	GI	Zn	Al
Rural					
1	Aligarh	0.015904	0.002779	0.0022627	0.0005377
2	Bhopal	0.00982	0.000117	0.000356	0.000223
3	Bhubaneswar	0.0244	0.001492	0.0008265	0.0007313
4	Chandigarh	0.02144	0.001616	0.0012	0.0001376
5	Dindigul	0.016972	0.002084	0.004958	0.0000012
6	Jorhat	0.007439	0.001047	0.0008806	0.0000498
7	Karaikudi	0.01997	0.000381	0.0011	0.0003947
8	Mahendragiri	0.01357	0.00352	0.00625	0.00532
9	Warangal	0.009843	0.0065	0.002805	0.0000584
10	Salem	0.01616	0.0014	0.001655	0.0000128
Industrial					
11	Coimbatore	0.016		0.001	0.004
12	CECRI Unit, Kochi	0.0905	0.00286	0.00253	0.00018
13	Manali	0.115	0.00456	0.0238	0.00141
14	Mettupalayam	0. 300		0.007	0.009
15	Mumbai	0.044	0.0036	0.0026	0.0025
16	Tirupur	0.018		0.0001	0.003
17	Vishakapatnam	0.03669	0.00275	0.0036	0.00485
18	Kolkatta	0.0226	0.001754	0.00129	0.0002313

Table 3. Atmospheric corrosion rate of mild steel (MS), galvanized iron (GI), zinc (Zn), and aluminium (Al) at various exposure stations in India, based on one year's data, reported in mmpy.

Marine					
19	Naval base,Chennai	0. 524	0.01166	0.0071	0.0086
20	Cuddalore	0.0513	0.0042	0.0022	0.001162
21	Kakinada	0.0820			
22	Kanyakumari	0.01564	0.002489	0.00196	0.003116
23	Kayankulam	0.0420	-	0.003	0.0005
24	Kochi	0.1566	0.006445	0.006304	0.00087
25	Mandapam Camp	0.10905	0.01255	0.01215	0.0007
26	Mangalore	0.1084	0.00671	0.00137	0.0051
27	Morumogao	0. 4539	0.1841	0.019412	0.011
28	NIO GOA	0.03	0.00226	0.00126	0.000248
29	Nagapattinam	0.0289	0.000322	0.0027	0.00001
30	Padubidri	0.0430		0.002	0.0014
31	Pondicherry	0.02742		0.000992	0.0001
32	Port Blair	0. 38	0.27	0.22	0.04
33	Sriharikota	1. 60		0.0460	0.029
34	Tuticorin	0.08381	0.02448	0.0322	0.0271
Urban					
35	Bhavnagar	0.01273	0.000402	0.0003849	0.00018501
36	Hyderabad	0.023511	0.002360	0.0025564	0.0004342
37	Lucknow	0.01232	0.0073438	0.005067	0.007279
38	New Delhi	0.01977	0.002845	0.00056	0.0002948
39	Pune	0.0124	0.00242	0.00148	0.000032
40	Surat	0.0273	0.00254	0.00208	0.00393

the corrosion rate may vary widely from place to place, and therefore the performance of aluminium is more area-specific than mild steel, zinc, and galvanized steel.

Durability factors

The durability factor is defined as the ratio between the corrosion rate of mild steel and that of a non-ferrous metal exposed in a particular spot. The durability data have been analyzed and presented in the form of durability maps of India, and are shown in Figs 6-8. This is an important parameter, which will be of considerable help to designers in the selection of durable engineering materials for a particular area; proper selection of engineering materials can lead to great savings. Figures 6-8 clearly indicate that non-ferrous metals (including galvanized steel, zinc, and aluminium) have better durability factors than bare mild steel. However, these factors vary from place to place, in the range 1.4-90, 2-180, and 2 to above 2890, for galvanized steel, zinc, and aluminium, respectively. Very high durability factors for zinc were observed at Tirupur, and the lowest durability was at Port Blair; for galvanized steel, the highest durability factor was observed at Nagapattinam Port, and the lowest was also at Port Blair; for aluminium, a very high durability factor was observed at Dindigul, Nagapattinam Port, and CECRI Unit Kochi, and the lowest range was observed at Mahendragiri. These durability data were determined from one-year corrosion data; generation of long-term data will yield a more-realistic picture of relative durability.

Particularly in the case of aluminium, long-term exposure may sometimes lead to localized corrosion. If the durability and cost factors are taken together, it can be clearly seen that aluminium has an appreciable cost-benefit ratio. although at certain locations galvanized steel may prove to be a more cost-effective candidate materials.

Conclusion

The atmospheric corrosivity of mild steel, zinc, galvanized steel, and aluminium were determined at 40 exposure sites located throughout India. The data collected from these field locations have been analyzed and are presented in the form of updated corrosivity and durability maps of India, dated 2004. The interesting feature of these maps is that the corrosion is area-specific, and not region-specific. Durability factors for non-ferrous metals clearly indicate that galvanized steel, zinc, and aluminium have better durability factors than bare mild steel.

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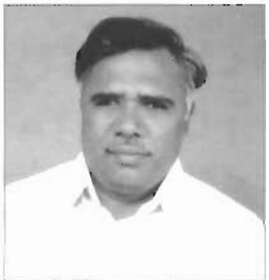

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