

CORROSION OF STEEL IN THE MARINE ENVIRONMENT AND ITS PREVENTION WITH SPECIAL REFERENCE TO TRAWLERS

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The corrosion behaviour of metals and alloys in various environments forms an important study. The corrosion of metals may be broadly defined as a chemical or electro-chemical reaction between them and their environment which results in their deterioration and destruction. Such a wastage of metals due to corrosion is one of the most important engineering problems today. The performance of all construction materials in the marine environment has been closely observed and studied for well over 200 years now as a result of which it is known that the marine environment is highly destructive and deteriorates most of the materials, iron and steel in particular. With the advent of modern steel trawlers coming into operation in large numbers for deep sea fishing activities in India, an attempt is made in this paper to review the behaviour of steel in the marine environment.

Carbon steel, alloy steels and cast iron are the most important materials of the ferrous group that have great and constant demand for ship-building purposes. These materials irrespective of their vary-

ing mechanical properties and diversified application, are prone to corrosion, both of the atmosphere and sea-water. The behaviour of ferrous metals as they corrode by a uniform general surface wear accompanied by surface pitting under marine atmosphere and in sea-water is quite distinct from the non-ferrous metals (copper, Aluminium, Zinc, magnesium etc.) in which case the corrosion products form a firm protective layer on the surface of the metal and prevent further action. The corrosion product of steel is rust (iron oxide) which is generally porous and does not have much of self-protecting effect and hence the steel surface below the layer of rust remains open to a large extent for new corrosion attacks.

Steel always contains *Carbon* in varying quantity in the form of *graphite* or in chemical combination with *iron* in the form of cementite. Furthermore, the presence of non-ferrous metals (Copper, Zinc), non-metallic elements (phosphorous, Silex, Sulphur) and other waste metals play an important part in the rusting process. Coastal India has varying climatic

conditions and it is highly important to assess exactly the type and rate of corrosion in various localities and under different fluctuating conditions. Tons and tons of iron and steel (quoted price at Rs. 1,600/- per ton but in the market it is Rs. 3,300/- per ton!?) are exposed to corrosive elements prevalent in the highly industrial or marine areas (unlike the rural environment, the industrial and marine environment are highly corrosive). The various parameters such as temperature, humidity, oxygen availability, rain fall, air pollutants etc. play a vital role and have profound influence on the corrosion rates. Sulphur-dioxide and aqueous salt solutions are the true representatives of corrosive factors of the industrial and coastal atmospheres respectively. Underwater corrosion of steel is governed by physical, chemical and biological properties of sea-water.

Sea-water corrosion is more drastic than that under atmospheric conditions, as sea-water provides low electrical resistance and offers an excellent environment for galvanic corrosion to take place. If two different metals or alloys are in contact with an electrolyte (sea-

NOTE: In view of the topical interest of the present technical article, Part III of the series 'On the Characteristics of Some of the Indian Timbers for Boat Building' by the above author will appear in the next issue of this journal.

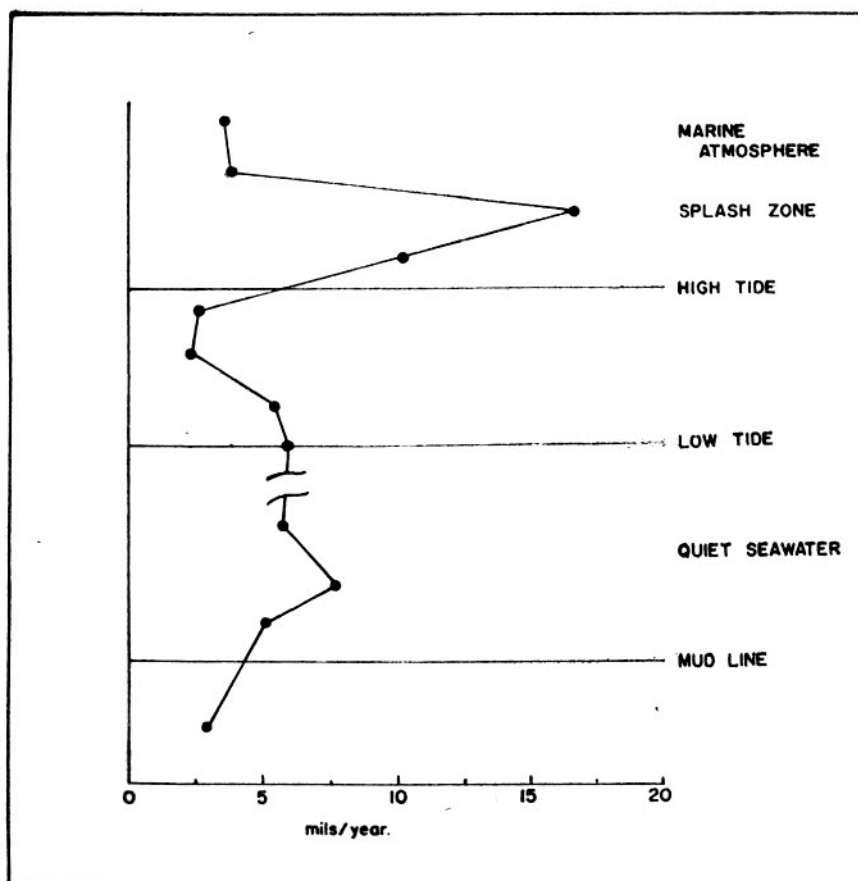


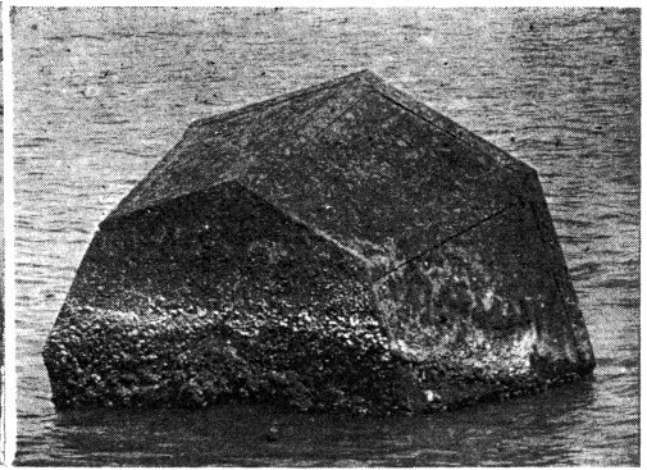
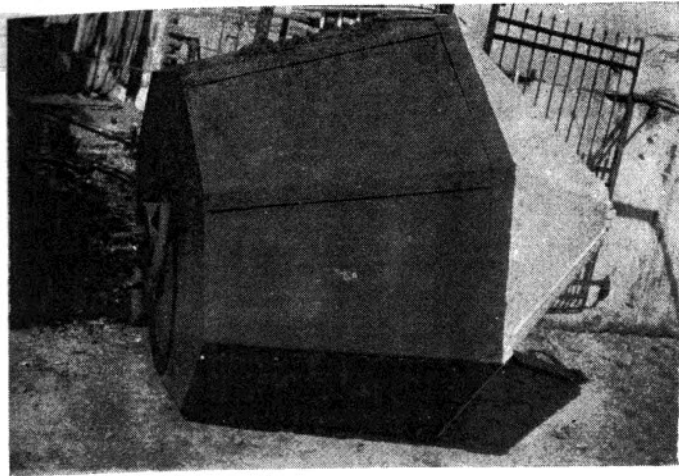
Fig. I - Typical corrosion rate of steel in aerated sea-water
(1 Mil = 1/1000 inch)

water), the less noble metal (iron and steel) is affected while the more noble (copper and its alloys) is protected. The oxide or the corrosion appears at the affected anode of the galvanic element. Average rate of corrosion of steel and iron under immersed condition in sea-water works out to be 0.006 ipy (as expressed in inches penetration per year) under normal conditions. Higher rates of corrosion have also been recorded under peculiar circumstances and environmental conditions due to accelerating factors. The aeration of sea-water will increase the rate of corrosion of steel considerably. Under immersed condition, the increased supply of oxygen being the causative factor for the enhan-

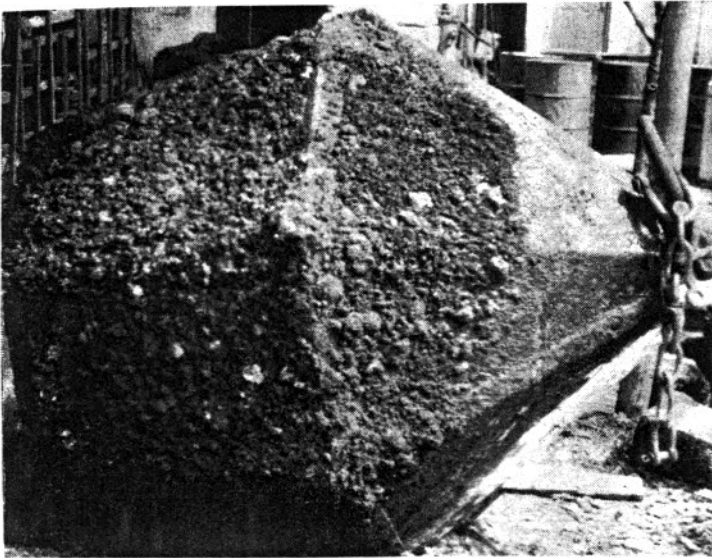
ced corrosion. At a higher pH value of the sea-water, the immersed steel will corrode severely. The corrosion of steel by sea-water will increase as the velocity increases. 50% more of corrosion on steel will be there if it is in contact with copper and similar other noble metals in sea-water. The weight loss of steel under continuous immersion in sea-water is for all practical purposes a linear function of time. Severe accumulation of marine growths (animals and plants) on immersed steel plates under continuous immersion in sea-water and certain marine bacteria are also the active agents in the acceleration of corrosion. (Data for Cochin Port is presented in Table I).

The ship building industry requires special type of steel for use. Carbon steel (Mild Steel) is the basic material for ships' hulls, harbour structures, port piles, buoys and most other large items of equipment in a marine environment. The conventional mild steel has a yield strength of 15 tonnes per square inch and is normally used as wrought sections, plate and fasteners. Steel with small alloying additions can increase the yield strength to about 20 to 22 tons per square inch besides enhancing their resistance to marine corrosion. Some of the specially alloyed steels will possess corrosion resistance 4 to 6 times more than that of ordinary mild structural steel. Atmospheric corrosion resistance of low alloy steels is about double that of mild steel but under conditions of total immersion in sea-water there is very little difference between these two materials. However, the sea-water corrosion of steel can only be controlled by external factors rather than by the composition of the steel since none of the common alloying elements has any commercially significant influence on the under-water corrosion of steel.

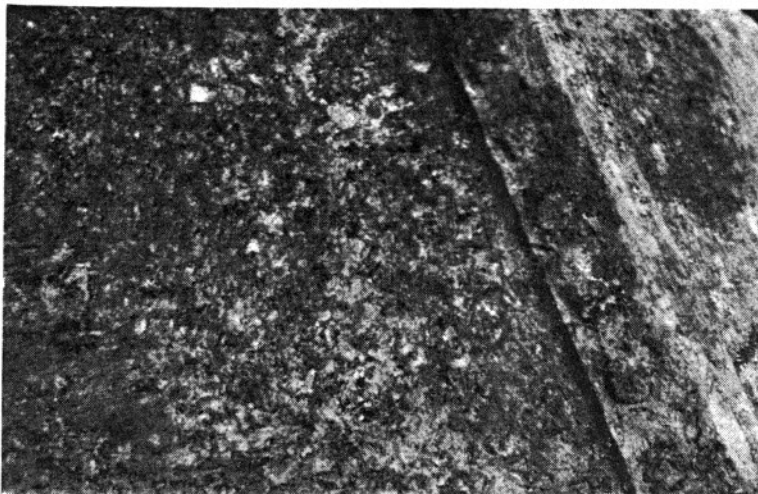
Prevention of corrosion is not too very difficult if proper precautions are taken well in time. Ideally, the prevention of corrosion should be thought of even at the design drawing table. Designers, construction staff and ship-builders should be aware of the sea-water galvanic series which will be a basic guiding factor as to the behaviour of the various common metals and alloys used for construction in sea-water and marine atmospheres. The protection of metals by paints as an anticorrosive measure offers many technical problems calling for constant research and development. To



A brand new steel buoy painted and ready for immersion test (left). A floating buoy at the test site showing pattern of floatation and zonation of fouling (right).



The Buoy hauled ashore after 18 months showing the general condition of fouling (left.) A close up view showing the fouling by oysters and Barnacles (shell forms) with a deposit of silt (right).



<-- Condition of steel after all the fouling removed showing severe corrosion in patches and all protective paints gone.

combat corrosion successfully and economically specially designed and formulated paints alone will serve the purpose. In order to specify the right protective lining or coating to meet a given set of corrosive conditions, one should be well versed not only in the properties of these many materials, but in their limitations as well. Paints can control the corrosion of steel in two ways : by forming a physical barrier between the corrosive salts and the steel surface, and by the effect of certain pigments which inhibit the corrosion reactions at the metal surface. A paint film that is comparatively resistant to the ingress of moisture and oxygen, will give the best protection against corrosion.

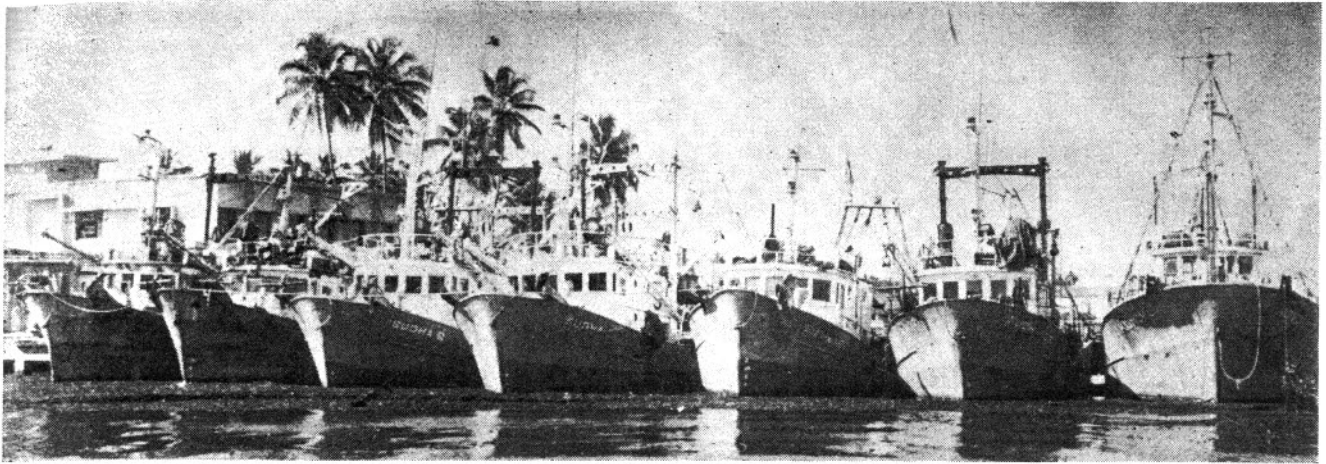
Steel surfaces have to be thoroughly cleaned before any protective painting is attempted. Apart from the quality of the paint, careful removal of rust, mill scale, salt, oil, grease, dirt and loose paint if any from the surface is the most important single factor deciding the length of effective service of the paint system adopted. Steel surfaces are usually cleaned by manual chipping, scrapping, wire brushing and cleaning or by any standard method of blast cleaning (sand or grit blast, flame blast etc.). Steel exposed with rust and mill scale will be pitted about three times as deeply as descaled steel under identical conditions of exposure. Metal spraying after grit blasting and thorough cleaning is a well established means of providing long term protection to steel in spite of the initial high cost of surface preparation and the subsequent blasting. The cheapest and the most effective of the metals for the protection of steel are aluminium, and Zinc and they account for at least 90% of sprayed protective coatings. The life of

this protective scheme can also be extended both by metal spraying coupled with surface painting. The protective paints are the conventional oil based paints, the alkyd resin paints, the polyurethane paints, the epoxy paints, the vinyl paints and the synthetic rubber paints. Some of the sophisticated paints which give assured performance when applied as specified are comparatively costlier as their use in India at present involves imports.

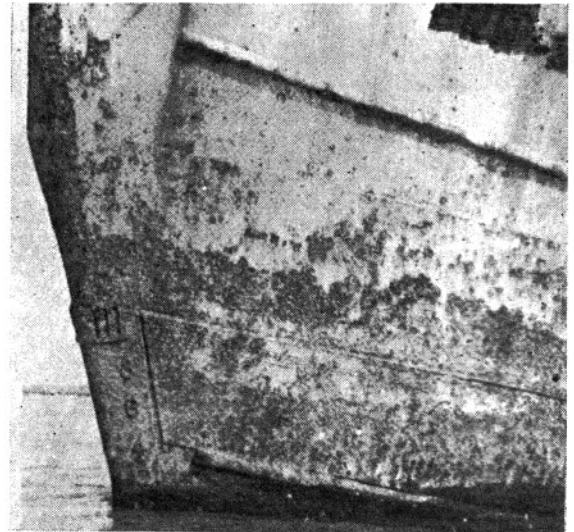
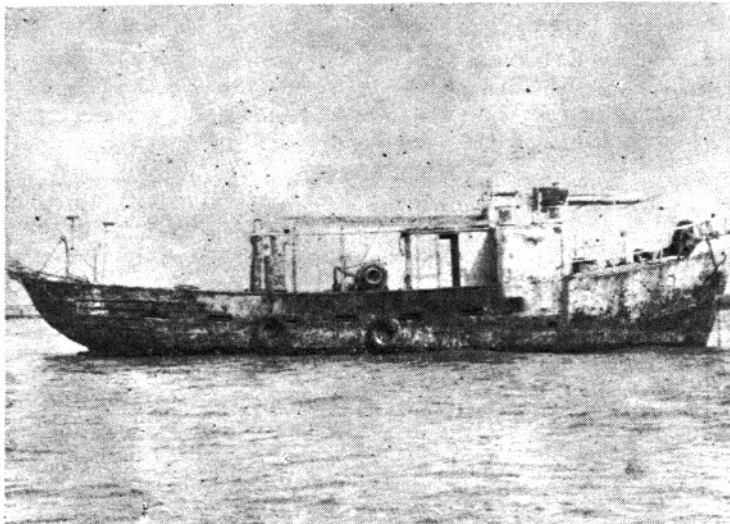
Painting of steel trawlers in particular is a special aspect of protective painting of steel under varying conditions. The hull surface above water-line is exposed to marine atmospheric corrosion while the hull immersed below water-line is subject to sea-water corrosion. In between these two is the more severe zone for corrosion than the fully immersed or completely exposed zones. This—the “Boot-topping” area is the ship's high and low water line which is subject to alternate wetting and drying besides the constant splashing of sea-water and exposure to salt laden atmosphere. Protective coatings tend to fail first in the splash zone and are difficult to renew effectively in these areas. A specialised painting schedule is necessary to protect this area which normally suffers from corrosion and erosion. Engine room, cabins, lockers, cargo holds and bilges may require yet another system of painting suiting to the exact needs. The painting system for the under-water steel hull should necessarily ensure proper adhesion of the priming coats, should have good electrical insulation to prevent the free passage of current between anodic and cathodic areas, must resist saponification under immersed condition in an alkaline environment.

The stern quarter of ships consisting of the bronze propeller, steel rudder, steel hull, propeller shafts and their supports are subject to severe corrosion due to galvanic action of the noble metals as well as due to high turbulence caused by the rotating propeller. Paints are not normally stable in these areas. It has been estimated that corrosion in these critical zones increases as the sixth power of the velocity and as such with any increase in the speed of the ship the rate of corrosion also increases. However, a combination of paint and a suitable system of cathodic protection (installation of *magnesium, Zinc* or *Aluminium* anodes) usually gives the most economical safeguard at the stern areas of steel ships. Since all conventional antifouling paints always contain either copper or mercury salts as the toxic ingredients, their direct application on unprotected steel hulls will accelerate corrosion of the latter by galvanic action and hence suitable barrier paints are essential for proper insulation. In heavily fouled ships, the dead decomposing fouling organisms on the steel hulls might release organic sulphur compounds and *hydrogen-sulphide* which are very active corrosion accelerators. This has to be prevented by keeping the hull free from fouling through systematic cleaning and painting at the time of annual dry-docking.

The protective ability of a paint system is entirely dependent on its being applied to the correct thickness to the correct material after the required surface preparation. A consolidated film thickness of at least 8-10 mils (1 mils = 1/1000 inch = 25.4 microns) on the underwater steel hull, 6-8 mils on the boot-topping area, top sides and decks and at least 4-5 mils on super structures will give the



A fleet of steel trawlers well maintained and free from corrosion.



A heavily corroded steelhull of a trawler. (left) Unstable point and heavy corrosion at the splash and wind-water zone of a steel trawler. (right)

desired protection against corrosion in steel trawlers. This protective painting system should cover metal wash primer, metal primer, anticorrosive and anti-fouling paint coats.

It is thus clearly evident that ordinary iron and steel are highly susceptible to corrosion in both coastal atmosphere and sea-water and yet they have by far the greatest use because of the factors of cost and their important

physical properties outweigh all the others. Marine corrosion and its prevention is a complicated subject. Corrosion is an insidious enemy in steel trawlers. When signs of rust are detected, preventive measures have to be taken immediately. Do not wait until rust has ravaged the ship beyond recovery. The United States of America incurs an annual loss of 5 billion dollars due to corrosion. Corrosion and its prevention cost India Rs. 150/- crores a year. War against corrosion is never ending.

The Craft Materials Section of the Central Institute of Fisheries Technology at Cochin is currently engaged in investigating the causes of corrosion in fishing boats with a view to suggesting economical preventive measures and to standardise material selection, fleet management and service maintenance. Careful selection of the right materials, proper construction and periodical maintenance will mean more useful life out of our trawlers.

TABLE I. Showing the fluctuating environmental factors likely to influence marine corrosion of steel in and around Cochin Port, Kerala, India with special reference to Steel Trawlers.

Environmental factors	Max./Min.	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	Other influencing factors
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Marine Atmospheric Temperature in 0°C	Max. Min.	30.0 27.5	31.0 29.0	32.0 28.0	32.6 29.0	32.5 27.2	31.2 26.0	30.8 25.1	31.9 27.0	30.5 25.2	31.2 26.6	31.0 27.8	31.1 27.5	Turbidity due to suspended matters fluctuate between 2.5 ppm to 35.5 ppm.
Surface Sea-water Temperature in 0°C	Max. Min.	29.5 27.0	30.8 28.0	32.0 30.2	32.4 30.4	33.0 29.2	31.2 26.5	29.6 26.0	30.0 27.0	29.7 26.0	31.2 28.2	31.0 28.5	30.9 27.8	Normally the surface velocity of sea-water reaches a speed of about 2 to 4 feet per second reaching 8 feet per second at times.
Sea-water Salinity %0	Max. Min.	33.8 21.9	34.6 28.0	34.7 28.6	35.0 28.3	35.3 25.7	29.3 2.60	4.15 0.68	10.48 1.20	13.50 2.65	13.50 3.58	22.60 10.40	25.26 24.16	
Dissolved Oxygen MI/L	Max. Min.	6.2 3.4	5.8 3.4	5.4 2.8	4.4 1.2	6.6 1.4	6.8 2.8	7.6 3.6	7.0 5.4	8.0 5.0	7.8 4.4	6.0 2.2	6.8 2.6	Marine fouling due to barnacles, oysters, tube-worms, hydroids and algal growths are moderate to heavy during all the months except during June, July, August and September when it ranges from practically nothing to only meagre.
Sea-water PH	Max. Min.	7.7 7.0	8.1 7.0	8.2 7.0	8.2 7.2	8.2 7.3	8.1 7.2	8.2 7.0	8.2 7.0	8.1 7.0	8.1 7.1	8.2 7.1	7.9 7.0	
Rainfall in inches	Average	0.8	2.0	3.0	7.0	12.0	25.0	24.0	19.4	14.0	15.0	9.0	3.0	
Relative humidity %	Max. Min.	96.0 57.0	80.0 57.0	92.0 66.0	81.0 68.0	91.0 66.0	91.0 77.0	93.0 80.0	88.0 73.0	96.0 73.0	91.0 66.0	88.0 66.0	88.0 63.0	All the aforesaid factors are very suggestive that the corrosion of steel hulls will be more than normal in and around Cochin waters and as is seen in the illustrations.