Proceedings of the
International Conference on Mechanical Engineering 2003
(ICME2003) 26- 28 December 2003, Dhaka, Bangladesh

ICME2003-AM-17

SURFACE CORROSION OF MILD STEEL STRUCTURES

M.T. Islam[1] and M.A. Chowdhury[2]

[1]Mechanical Engineering Department, Chittagong University of Engg & Tech., Bangladesh
[2]Chittagong Dry Doc Ltd., Bangladesh

ABSTRACT

Steel structure surface corrosion is vast in nature. All mild steel structure surfaces have been prepared for painting or hot-dip galvanization after fabrication works to prevent corrosion. The main objective of this study was to find out wearing nature of average corrosion resistance steels with well-painted or hot-dip galvanization or cold galvanization in the humid environment. The experiment was carried out in a bath of humid environment where painted, cold-galvanized and hot-dip galvanized specimens (size: 50x50x4 mm x 14 mm length) have been exposed for 250 hours keeping temperature 60°±2°C as per ASTM G 31-72. Alkometer has measured every 50 hours interval after disposal specimens from the bath, the worn film thickness in micron. Finally corrosion rate (in µ mm penetration per year) was calculated for the said specimens. Environmental effects on these specimens have been properly watched. Hence cold galvanized mild steel was found more preferable for use in humid environment than painted or hot-dip galvanized steel.

1. INTRODUCTION

Chittagong Dry Dock Ltd (CDDL)[1] is mainly a ship-repairing enterprise. Even though, it has been fabricating different kinds of heavy steel structures, such as, portable steel bridges, gangways, pressure vessels/tanks, towers, trusses, etc for 30% fulfillment of yearly turnover beyond ship-repairing works. Portable steel bridges have been mostly consumed by LGED, Chittagong Hill Trucks Development Board, Bangladesh Military, Chittagong City Corporation, Chittagong Port Authority has used Bangladesh Tea Board and Illuminating towers. The fabricator wants to make their quality product at minimum cost and also the buyer seeks to have the quality product of lowest cost for which all steel structure surfaces have been prepared for painting or hot-dip galvanization after fabrication works.

There are many kinds of structural steel standard having different contents of chemical composition and strength. Chittagong Dry Dock Limited has been using a few standard of which is ASTM A36, JIS G 3101, JIS G 3106 (average corrosion resistance steels). High corrosion resistance steel likely as, JIS G 3114 is very costly (70%--80% higher than average steels). CDDL is thinking to diversify the motive of the customers towards the uses of average corrosion resistance structural steels to be cold galvanized because of cold galvanization is equivalent or rather higher grade of BS 729 hot-dip galvanization with minimum 12 years guarantee and easy to apply, as like as painting. Thus, CDDL already introduces average corrosion resistance steel products with cold galvanization by ZINGA (made in Belgium) to their regular customers.

!.1 Mild Steel

Mild Steel has an ultimate strength of somewhere in the region of 29 to 30 ton/in^2, a modulus of elasticity about 13000-to13500 ton/in^2, a yield strength of 15 to 16 ton/in^2 and very ductile properties [2]. The good properties of mild steel are: relative cheapness of production, high mechanical properties, ease of cold working and ability to be hot worked without loss of mechanical properties. It has the disadvantage that it requires efficient protection to prevent corrosion. When riveted construction gave way to welding it eventually became possible to mild steel easily and high efficiency joints could be obtained. The mild steel has a chemical composition mainly iron with the addition of small percentages of other materials, principally carbon and manganese. The percentage of carbon is usually somewhere about 0.2% and in modern steels, the manganese content is not less than 2.5 times the carbon content. Impurities such as sulphur and phosphorus are kept at a low level, usually 0.05% for each. The addition of carbon and manganese is responsible for the superior mechanical properties of mild steel as compared with iron.

1.2 Constitutions and Structure of Steel

As a result of the methods of production, the following elements are always present in steel: carbon, manganese, phosphorus, sulfur, silicon, and traces of oxygen, nitrogen, and aluminum. Various alloying elements are frequently added, such as nickel, chromium, molybdenum, and vanadium. The most important of the above elements in steel is carbon, and it is necessary to understand the effect of carbon on the internal structure of steel to understand the heat treatment of carbon and low-alloy steels. Pure iron when heated to 910°C changes its internal crystalline structure from a body-centered cubic arrangement of atoms, alpha iron, to a face-centered cubic structure, gamma iron. At 1390°C, it changes back to the body-centered cubic structure, delta iron, and at 1539°C the iron melts. When carbon is added to iron, it is found that it has only slight solid solubility in alpha iron (less than 0.001 % at room temperature). On the other hand, gamma iron will hold up to 2.0% carbon in solution at 1130°C. The alpha iron containing carbon or any other element in solid solution is called ferrite, and the gamma iron containing elements in solid solution is called austenite. Usually when not in solution in the iron, the carbon forms a compound Fe_3C (iron carbide) that is extremely hard and brittle and is known as cementite.

2. STEEL SURFACE CORROSION

Corrosion is a destructive attack on steel surface, which may be chemical or electrochemical in nature. Direct chemical corrosion is limited to unusual conditions involving highly corrosive environments or high temperature or both. However, most of the phenomena involving corrosion of metals [3] containing or submerged in water, or atmospheric corrosion by films of moisture are electrochemical in nature. We, here think about atmospheric corrosion, because of exposed steel structures [4](bridges, trusses, towers, etc.) are used in open space of Bangladesh. Atmospheric corrosion is stimulated by humidity, damp atmosphere, since these maintain a film of water on the metal, providing the essential electrolyte. Other factors are acid gases in the atmosphere or sulfur compounds from cinders, coke, coal dust, etc; salts dissociate to produce an acid reaction; oxygen dissolved in the water film [5]. Rust may accelerate corrosion and cause pitting. The probable explanation is that surface accumulations of rust shield the underlying metal from free access to oxygen, thus rendering such portions anodic (corrodible) with respect to unshielded areas to which oxygen has freer access (cathodic areas).

2.1 Methods for Minimizing Corrosion

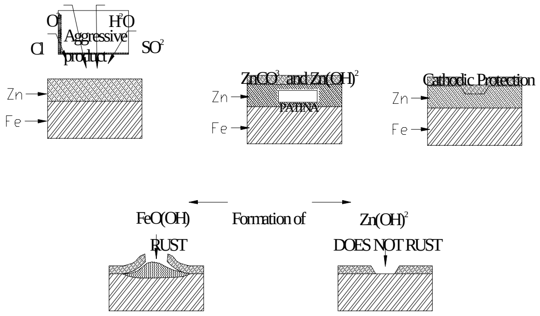
With few exceptions, any marketable product of low carbon steel must be surface-finished by grit/air/sand blasting or acid pickling for good adhesion before any coating for surface protection [6]. While the primary purpose of a coating or finish may often be to improve the appearance and sales of the item, coatings must be used on metals to give reasonable resistance to destructive influences due to wear, electrolytic decomposition and contact with the weather or corrosive atmosphere [7]. Corrosion may be minimized by (1) the use of a coating of protective metal such as zinc; (2) the production of oxide, phosphate, or similar coatings on iron and steel surfaces; (3) the application of protective paints; and (4) rendering the surface of the metal passive. Here we consider surface protection to be processed by (1) the application of paint, or (2) metallic coatings.

Paint coating: Paint coating [8] is not expensive, but it is required to prepare surface properly by grit/air/sand blasting. This type of coating has minor life due to which every two years interval new coatings are needed as experienced by Chittagong Dry Dock Ltd. The ingredients of paints are drying and semi drying vegetable oils, resins, plasticizers, thinners (solvents), dryers or other catalysts, Portland cement and pigments [90. Paint systems for steel surface [11] usually consist of one or two coats of rust inhibitive primer and one or more finish coats, selected according to severity of conditions. The primer contains one or more rust-inhibitive pigments, selected mainly from red lead, zinc yellow and zinc dust. It may also contain zinc oxide, iron oxide and extender pigments. Of equal importance is the binder, especially for the topcoats. Actually paint is a mixture of filmgoer (film-forming material, binder) and pigment. The pigment imparts color and the filmgoer, continuity; together, they create opacity. Heavy dew, hot sun and marine atmospheres shorten the life of paint.

Metallic coatings [11]: Metallic coatings are in general, the application of a finite thickness of some material over the metal, or are the transformation of the surfaces by chemical or electrical means to an oxide of the original metal. Galvanizing is a zinc coating used extensively for protecting low carbon steel from atmospheric deterioration. Galvanizing by zinc is generally applied to metal surfaces by the Sherardizing process, by dipping into a bath of molten zinc, by electrode position, or by metal spraying. But we here consider (1) the hot-dip galvanizing process and (2) a new technique--the cold-galvanizing process.

Hot-dip galvanizing [12]:In the hot process, the articles after being thoroughly cleaned by acid are dipped into a bath of molten zinc. The bath must be maintained at a temperature somewhat higher than the melting point of zinc, which requires a large fuel consumption and also results in a loss of zinc (approx. 10%) a greater source of loss is the iron-zinc alloy which forms as a heavy sediment in the zinc bath. The process is used almost exclusively for sheet and pipe and until recently, for wire also. Exposed structural-steel components (of reasonable length and size due to bath scarcity), such as towers, are zinc-coated by this means. A coating applied by hot dipping never consists of a simple layer of zinc. It is always of a composite nature, the layer adjacent to the base metal consisting of zinc-iron alloys. This layer is relatively brittle and thereby, imposes some limitations on hot-dipped galvanized steel materials.

Cold galvanizing: Cold galvanizing compound coatings [13] are applied on steel as a means of providing cathodic protection. Cathodic protection arises from the zinc (the anode) sacrificing itself in favor of the base metal (the cathode). The protection of the metal by Zinc-coating by this process is widely appreciated in the whole world. Even when the zinc layer is slightly damaged, there is no rust formation underneath. Traditional zinc galvanizing (hot-dipping) techniques are difficult to apply on-site, but Cold-galvanization can be done as easily as a painting. Paints form a barrier to the air. Once the barrier is broken, however, rust will spread under the paint and will cause flaking. Most so-called zinc-rich paints do not solve this problem, mainly because they do not contain enough zinc to ensure adequate cathodic protection. Cold-galvanization protects against rust in two ways: i) galvanic protection (cathodic/sacrificial) ii) protection by means of a barrier (organic paint layer) Cold-galvanization combines the galvanic characteristics of a zinc coating with the barrier protection of an organic paint, as it has 96% pure zinc in its dry film which provides excellent cathodic protection to steel. It is safe and easy to use. It is a one-pack coating system that can be brushed, sprayed, immersed. Cold-galvanization can be done to recoat existing hot-dip galvanizing in order to renew the cathodic protection. It is not always necessary to grit-blast surfaces. Cold-galvanization can be applied on mildly rusty surfaces after they have been degreased and loose rust has been removed. Existing coatings of zinc (by Cold-galvanization) can be coated with a new zinc coating (with the same good result as the original coating). Cathodic protection reduces maintenance costs, compared to non cathodic protection. The figure shows how cathodic protection works :



The film galvanized system Cold Galvanization is a high quality and high performance industrial approach for the conquering of any corrosion problem for all ferrous metal so far.

Non Cathodic (Paint System) Protection Layer Cathodic (Zinc System)

$Fe \rightarrow Fe^{2+} + 2\,^{e-}$ $Zn \rightarrow Zn^{2+} + 2^{e-}$

Reaction with Air & moiture

$O_2 + 2H_2O + 4e^- \longrightarrow 4(OH)^-$

$Fe \rightarrow Fe^{2+} + 2^{e-}$

$Fe).(OH) \longleftarrow Zn(OH)_2$

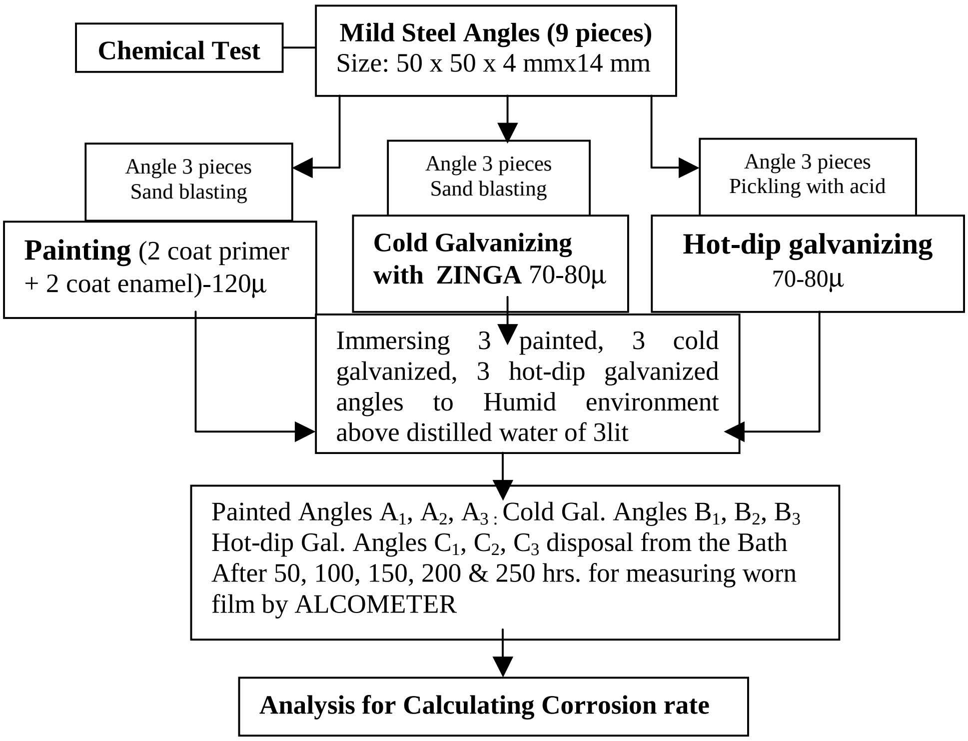
Table 1-Physical & Chemical Properties of cold galvanizing compound—ZINGA [4]

Zinc Content	96%
Zinc Purity Degree	99.995% (minimum)
Density	2.67 kg/dm3
Dry Extract	79.6% by weight
Temperature Resistance	-400 C to +1500 C
Drying Time	5 to 10 min
Spreading Rate	40 microns : 4 m2/ kg
Flash Point	470 C

ZINGA—Cold galvanizing compound originally from Belgium has been widely used in whole Europe for it's application easier in process without dismantling any structure and for above properties and guarantee. For example, famous Eiffel Tower was maintained by coating with cold galvanizing compound—ZINGA.

3. EXPERIMENT SET UP AND METHODOLOGY

3.1 Flow Chart:



3.2 Experiment Set

The experiment set is consisted with three polyvinyl bath of 27 cm ϕ x 33 cm height, each bath has heater element and thermostat to control the temperature. An accumulator is used to measure the coated film thickness and worn film thickness. 27 pieces M.S. angles (50x50x4mmx14mm length) are used for test specimen. Different tags (blue, red & brown) are used for identification of different experiments. The chemical composition of the M.S. angle (test specimen) P=0.05%, S=0.05%, Class-2 SS41, mechanical properties are yield strength 25 Kgf/ mm^2 (minimum) and tensile strength 41-52 Kgf/mm^2.

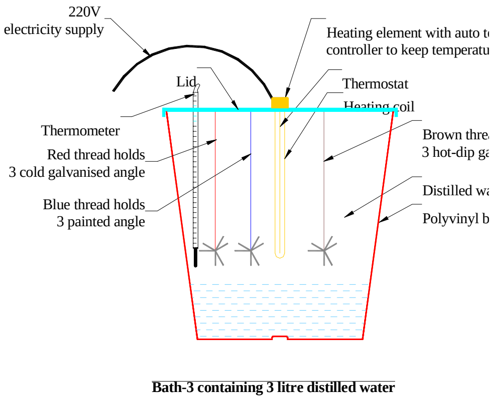


Fig.1 Experiment set up

3.3 Description of Experiment

M.S. angle is chosen which has been usually used by Chittagong Dry Dock Limited for it's production of portable steel bridge. The size of angle is 50x50x4 mm of suitable length. Chips are taken from the angle for chemical test. Chosen and tested angle is cut to 9 pieces, a little length of 14 mm each for the ease of experiment so that 3 bundle of specimens can be hanged into the Bath. First 3 specimens are sand blasted for surface preparation prior to painting. Then 2 coat primer film is applied maintaining a certain time interval for each coat as per instructions given. Similarly, these specimens are coated 2 times by enamel paint after prime coating. Film thickness is measured and recorded. Second 3 specimens are sand blasted for surface preparation prior to cold galvanizing as per instructions given in ZINGA-Brochure. Then these specimens are coated 2 times by applying cold galvanizing compound-ZINGA. Film thickness is measured and recorded. Third 3 specimens are pickled with acid for surface preparation prior to hot-dip galvanizing. Just after pickling, these specimens are exposed for a moment into molten liquid Zinc-Bath as per instructions given. Film thickness is measured and recorded. A cylindrical non-metallic (polyvinyl) bath (Humid Environment): Contains 3 liter distilled water with heating element (that is powered by 220 volt electricity supply source for keeping temperature of bath at 60°±2°C), in which 3 painted specimens, 3 cold galvanized specimens with red thread and 3 hot-dip galvanized specimens are hanged to immersing above from the distilled water (Fig:1a).

4. RESULTS AND DISCUSSION

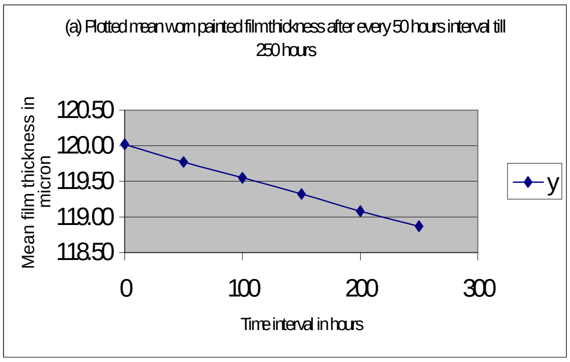
Table–2 Reduction of Film Thickness of Different Specimens

Hrs	Painted angles Film thickness		Cold-galvanized angles Film thickness		Hot-dip galvanized angles Film thickness	
		Average		Average		Average
0		120.02μ		79.98 μ		80.03 μ
50	A_1-119.77μ A_2-119.78μ A_3-119.76μ	119.77μ	B_1-79.97μ B_2-79.96μ B_3-79.98μ	79.97μ	C_1-79.92 μ C_2-79.93μ C_3-79.94μ	79.93μ
100	A_1-119.55μ A_2-119.56μ A_3-119.54μ	119.55μ	B_1-79.96μ B_2-79.95μ B_3-79.94μ	79.95μ	C_1-79.86μ C_2-79.85μ C_3-79.87μ	79.86μ
150	A_1-119.31μ A_2-119.33μ A_3-119.32μ	119.32μ	B_1-79.93μ B_2-79.92μ B_3-79.92μ	79.92μ	C_1-79.78μ C_2-79.77μ C_3-79.79μ	79.78μ
200	A_1-119.07μ A_2-119.09μ A_3-119.10μ	119.08μ	B_1-79.90μ B_2-79.89μ B_3-79.91μ	79.90μ	C_1-79.69μ C_2-79.71μ C_3-79.70μ	79.70μ
250	A_1-118.86μ A_2-118.88μ A_3-118.87μ	118.87μ	B_1-79.88μ B_2-79.87μ B_3-79.89μ	79.88μ	C_1-79.65μ C_2-79.63μ C_3-79.62μ	79.63μ

Corrosion rate of painted, cold galvanized and hot-dip galvanized angles disposed from BATH is calculated following way. It has been earlier mentioned that a humid environment in BATH-3 consists a little amount distilled water at 60°±2°C where different angles being immersed above surface of the water for 250 hours. After finding average worn of different coated angles, surface protection film (δ_m) to resisting corrosion are furnished. The graphs in Fig.2(a), 2(b), 3(a) & bar chart in Fig.3(b) are shown to differentiate worn film characteristics.

Corrosion rate of painted angles:
Worn Painted film after 250 hours,
$\delta_m = \delta_1 - \delta_2 = (120.02 - 118.87)\ 10^{-3}$ mm $= 1.15\text{x}10^{-3}$ mm
Corrosion rate = (δ_m x h.y)/T = ($1.15\text{x}10^{-3}$x 8760)/250 mm/yr = **$40.29\text{x}10^{-3}$ mm/yr.**
Corrosion rate of cold galvanized angles:
Worn Cold galvanized film after 250 hours,
$\delta_m = \delta_1 - \delta_2 = (79.98 - 79.88)\ 10^{-3}$ mm $= 0.10\text{x}10^{-3}$ mm
Corrosion rate = (δ_m x h.y)/T = ($0.10\text{x}10^{-3}$x 8760)/250 mm/yr= **$3.50\text{x}10^{-3}$ mm/yr.**
Corrosion rate of hot-dip galvanized angles:
Worn hot-dip galvanized film after 250 hours,
$\delta_m = \delta_1 - \delta_2 = (80.03 - 79.63)\ 10^{-3}$ mm $= 0.40\text{x}10^{-3}$ mm
Corrosion rate = (δ_m x h.y)/T = ($0.40\text{x}10^{-3}$x 8760)/250 mm/yr = **$14.01\text{x}10^{-3}$ mm/yr.**

Environment influences the metal surfaces, even the surfaces being protected with different types of film coating to resisting surfaces from corrosion [14]. Mild steel without surface protection coating is attacked by corrosion at normal atmosphere more rapid than other specialized steel. Normal atmosphere is defined as humid environment, which consists moisture content in the air. The moisture effects the steel surface gradually by corrosion. So, this environment is created in the Bath for above corrosion test purpose.



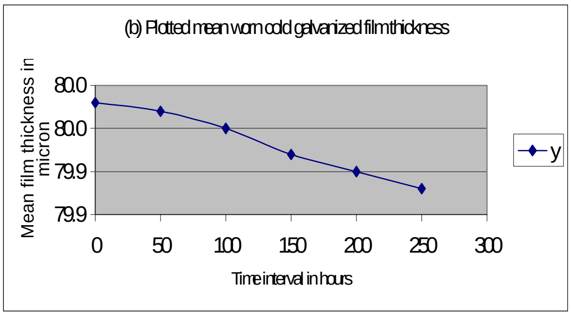


Fig.2 Reduction of film thickness of a) painted and b) cold galvanized in humid environment

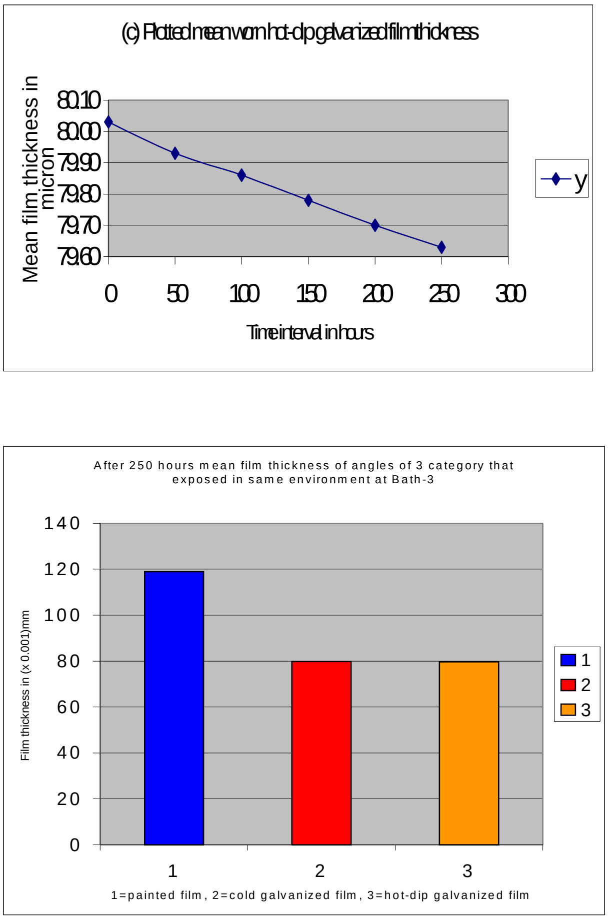


Fig.3 a) Reduction of film thickness of hot-dip galvanized angles in humid environment. b) Average worn film thickness with respect to time for (1) painted (2) cold galvanized & (3) hot-dip galvanized angles disposed from humid environment BATH

Metal surface with corrosion protection film is not more quickly effected by corrosion than bare metal surface. The different coated metal surfaces have been effected by corrosion in humid environment, is quantified, tabulated and represented in graphically. Then corrosion rates of different test pieces that effected by humid environment have been calculated. Which justifies environmental effect on steel surfaces. Though above analysis and result would support that cold galvanizing with ZINGA belongs to better durable in nature than painting or, hot-dip galvanizing for surface protection of steels

By Method, ZINGA is 4 times better than Hot-dip galvanizing as the test result of Bangladesh Engineering & Technology convinced and at the same time it is 25%--30% cheaper than Hot-dip.

In Bangladesh, Power Development Board introduced ZINGA—cold galvanizing compound for their maintenance work of corroded galvanized Towers by coating in the spot without dismantling any component. Chittagong Dry Dock Limited has been using cold galvanizing compound—ZINGA at it's premises as easy as painting for their fabricated portable steel bridges. So, in this perspective, enterprises of Chittagong would adopt cold galvanizing process for steel structures to save time and ultimately money.

5. CONCLUSION

In Bangladesh, many organizations use average corrosion resistance structural steel products with well-painted rather hot-dip galvanization for low cost even if the life of hot-dip galvanized steel is longer than painted steel. But scope of the use of the hot-dip galvanized steel products are limited due to time-factor, higher price, above all not guaranteed, though such products are assumed to contain much corrosion resistance capability. Thus necessity of the surface corrosion/wearing reduction of steel products is vital within limited cost, time and guarantee. Test and experiments for measuring corrosion rate of painted, cold galvanized and hot-dip galvanized specimens in humid environment are conveniently noticed. Where cold galvanized mild steel specimen is found more capable to resist corrosion indeed.

REFERENCES

1. Brochure of Chittagong Dry Dock Limited.
2. G.M.BOYD, "The Conditions for Unstable Rupturing of a wide plate," Trans. R.I.N.A., 1957, p.17.
3. WILEY , EVANS, "The Corrosion of Metals".
4. E. ARNOLD, FRIEND, "The Corrosion of Iron-Steel".
5. MACMILLAN, "Annual Reports of Committee A-5-Corrosion of Iron & Steel".
6. POLAR, "A Guide to Corrosion Resistance".
7. De PAUL, "Corrosion and Wear Hand Book".
8. KEANE Edition, Good Painting Practice.
9. ROBERTS, "Organic Coatings-their properties".
10. KEANE Edition, "Steel Structures Painting Council".
11. MARKS, " Standard Handbook for Mechanical Engineers," 8th Edition, McGraw-Hill Book Company, 1979.
12. M. L. BEGEMAN, "Manufacturing Process," Modern Asia Edition, Texas, 1956, pp. 123-125, 225-229.
    pp. 6-12—6-30.
13. ZINGA Cold Galvanizing Brochure.