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Over View Of Corrosion And Prediction Of Corrosion Ratein Cold Formed Steel Coupons

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Abstract:*Steel structures play a major role in structural components but corrosion has played a prime role in performance of these structures. Corrosion causes reduction in metal thickness which leads to reduction in ultimate load carrying capacity of the structures. Therefore it is necessary to design and maintain a structure to prevent corrosion in structures. Cold formed steel is extensively used in modern life as they are gaining more popularity compared to hot rolled steel. Thickness of cold formed steel components varies from 1mm to 6mm and they have have high strength to weight ratio. As the thickness is quite small the performance of these structures is effected by corrosion. The present work aims to study various issues related to corrosion, types of corrosion electrochemistry behind corrosion, chemical reactions and experimental investigations on cold formed steel subjected to electrochemical corrosion.*
Keywords:*Corrosion, Cold formed steel, Electrochemistry, Coupons , Steel structures*

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I. Introduction

Corrosion is a natural process which leads to a deterioration of steel structures. Corrosion reaction occurs through electrochemical reaction between the metal and an electrolyte through electrochemical reaction. Due to corrosion load bearing capacity reduces which leads to failure of structures. In India crores of rupees are lost every year owing to corrosion. In natural environment, metals are exposed to atmospheric corrosion, sea water corrosion and underground corrosion. Environmental factors like temperature, pressure, chemical composition, constituent concentration, PH value, electrical and thermal conductivity, viscosity etc, directly or indirectly, influence the corrosion process. Exposure of a steel structure to humid aggressive environment (rich in chloride and sulphate content) and improper protection and maintenance causes corrosion. Thickness /weight loss is the main parameter measured to quantify the amount of corrosion, which in turn affects geometric properties such as area, moment of inertia, radius of gyration and section modulus. A drastic reduction in mechanical properties such as yield and ultimate strength are observed for severely corroded members. Corrosion costs can be reduced by effective application of available corrosion control technology. Rahgozar et al. (2009) reviewed various forms of corrosion and the effects of uniform corrosion on steel structures and developed corrosion decay models [1]. Based on the studies conducted by Damgaard et al. (2010) it was concluded that corrosion can significantly reduce the service lives of steel girders [2]. New and improved corrosion control technology needs to be implemented which results from research and development. Therefore importance to study corrosion rate in cold formed steel is important. As a result in the present study cold formed steel corrosion coupons of size 1cm x 1cm were used to predict the corrosion rate.

II. Forms of Corrosion

Corrosion occurs in several widely different forms.
a)Uniform corrosion: It is also called general corrosion. The surface effect produced by most direct chemical attacks (e.g,by an acid) is a uniform etching of the metal. Reaction starts at the surface and proceeds uniformly.
b) Localized corrosion / Pitting corrosion: It is a localized form of corrosion by which cavities or pits are produced in the material. The basic metal is eaten away perforated in places in the manner of holes, the rest of the surface being affected only slightly.

c) Crevice corrosion: Crevice or contact corrosion is the corrosion produced at the regions of contact of metals with metals or non metals. It may occur at washers, under applied protective films, at sand grains and at pockets formed by threaded joints.
d) Stress corrosion: Stress corrosion is the growth of crack formation in a corrosive environment. It can lead to unexpected sudden failure of normally ductile materials subjected to tensile stresses especially at elevated temperatures.
e) Intergranular corrosion: It is a chemical or electrochemical attack on the grain boundaries of a metal. It often occurs due to impurities in the metal which tend to be present in higher concentrations near grain boundaries**.**
f) Galvanic corrosion: Galvanic corrosion is an electrochemical process, it occurs when different metals come in contact with each other when they are exposed to corrosive environment. The factors which effect galvanic corrosion includes type of metals, relative size of anode and environment (temperature, humidity, salinity etc).
g) Filiform corrosion: Filiform corrosion is a special form of corrosion that occurs under thin coatings in the form of randomly distributed thread like filaments. It is also called underfilm corrosion.
h) Exfoliation corrosion: Exfoliation corrosion is also called lamellar corrosion it is a severe type of intergranular corrosion that raises surface grains from metal forming corrosion products at grain boundaries under the surface.

III. Theories of Corrosion

(i) Homogeneous theory

On the metal surface presence or absence of any micro cracks are treated as a single electrode in which reactions occur. Metal becomes unstable due to which reactions occur at the interface. It is necessary that the potential difference across the interface is negative than the equilibrium potential for anodic reactions and positive for cathodic reactions.

(ii) Heterogeneous theory

According to heterogeneous theory local galvanic elements cause corrosion which leads to corrosion on metal surface as a result of chemical structure heterogeneity. Corroding metal consists of

a. An electron source area, where electronation reaction occurs.
b. An electron sink area, where de-electronation reaction occurs.
c. An ionic conductor to keep the current flowing.

IV. Electrochemistry of Corrosion

Although several mechanisms have been proposed for the corrosion process, corrosion is mainly electrochemical in nature . The corrosion reaction can be considered as taking place by two simultaneous reactions; the oxidation of a metal at an anode (a corroded end releasing electrons) and the reduction of a substance at a cathode (a protected end receiving electrons). In order for the reaction to occur, the following conditions must exist:

a. A chemical potential difference must exist between adjacent sites on a metal surface (or between alloys of a different composition)
b. An electrolyte must be present to provide solution conductivity and act as a source of material to be reduced at the cathode.
c. An electrical path through the metal or between metals must be available to permit electron flow.

V. Corrosion rate Expression

The rates of corrosion of metals are expressed as mpy (mills per year) or mmpy (millimeter per year). The relative scale for corrosion of metal as given by Fontana [3] as

Safe : Less than 0.125 mm/y.
Moderate : 0.125 mm/y to 1.25mm/y.
Severe : Greater than 1.25 mm/y.

The rate of corrosion of metal is usually measured by electrochemical methods. According to electrochemical method

$$\text{Corrosion rate (mm/y)} = 3.2 \times I_{corr}\ (\text{mA/cm}^2) \times \frac{\text{Eq. wt}}{\text{Density}}$$

The corrosion rate can be used to quantify the corrosion loss of a structural element which has been exposed to atmosphere corresponding to standard corrosion categories. Electrochemical reaction corrosion rate simulated in laboratory is always higher than the natural corrosion rate.

VI. Experimental setup for Corrosion

In the present investigation cold formed steel coupons of size 4cm x 4cm of 3mm thickness were used to predict the corrosion rate. The sample was abraded using SIC coated abrasive paper of different grades, 220 to 1500; then diamond paste was used to get a mirror finish and finally rinsing it with acetone and deionized water. The solution for the electrolyte was prepared by dissolving 35g of sodium chloride in 1000ml deionized water.

Fig 1: Polished cold formed steel coupons

The corrosion test was conducted in Autolab potentiostat and galvanostat (Nova 1.11) apparatus. The prepared solution was used in electrochemical cell in which cold formed steel coupon was implanted with an exposed area of $1cm^2$. Three electrodes, a reference electrode, working electrode and counter electrode were used. Polished steel coupon was used as working electrode, standard calomel electrode was used as reference electrode and platinum foil was used as counter electrode. All the three electrodes were placed in the cell containing corrosive solution for 30min and the corrosion potential, corrosion current, polorization resistance and corrosion rate were got as output from Autolab using Nova software package.

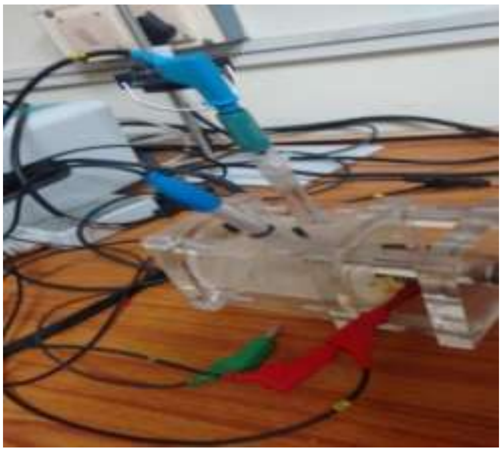

Fig 2: Autolab Potentiostat and Galvanostat Fig 2(a): Electrochemical cell

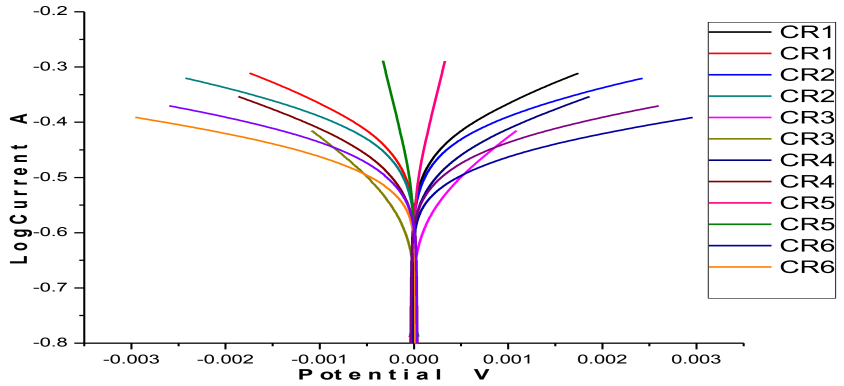

Fig. 3 Tafel plot for metal sample immersed in 3.5% Nacl solution

Anodic or cathodic tafel slope coefficients of a specific interface were determined from a log of current versus potential polarization diagram. Tafel plot was used to identify the corrosion susceptibility, rate of pitting and passivity. Nova software was used to make tafel plots. The curve fit is based on Butler-Volmer expression which allows more accurate determination of corrosion current, corrosion rate and polarization resistance. The corrosion rate is calculated from the estimated corrosion current obtained from the intercept of two linear segments of the tafel slope as shown in figure 5. The corrosion rate for six samples when immersed in 3.5%Nacl solution with respect to I_{corr} and E_{corr} is sumarized in Table 1. Variation in results is observed for a corrosion coupon with a minimum corrosion rate of 0.16206mm/y for sample number CC6 with polarization resistance of 1.66KΩ and a maximum corrosion rate of 0.2745mm/y with polarization resistance of 2.209KΩ for sample CC5. On an average of 0.2194mm/y corrosion rate is observed.

The Tafel equation is expressed as

$$I_{corr} = E_{corr} (ba + bc) / R_p$$

Where I_{corr} = Corrosion current
E_{corr} = Corrosion Potential
ba = Anodic current
bc = Cathodic current
R_p = Polorization resistance

Dissimilarity in electrochemical corrosion coupon results observed is due to imperfections present on the corrosion coupons. As corrosion current increases, increase in corrosion rate is noticed as shown in figure 4.

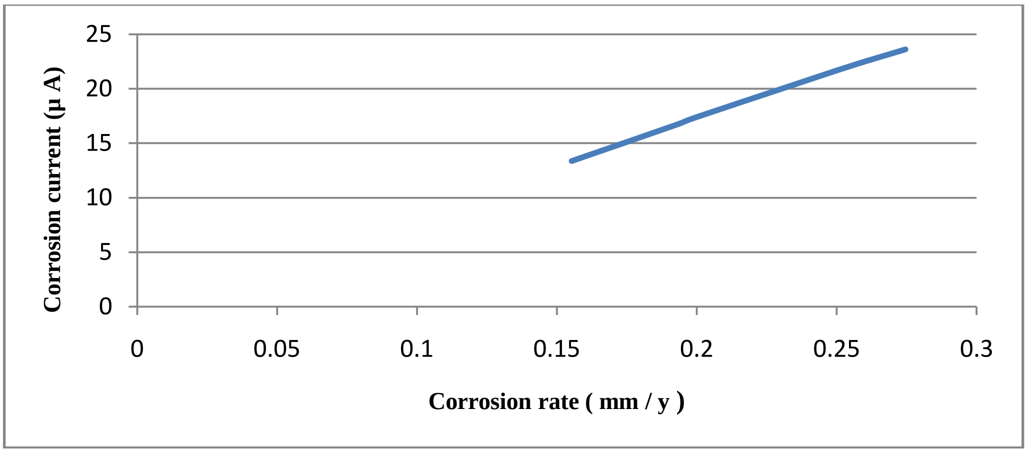

Figure.4 Prediction of corrosion rate with respect to corrosion current

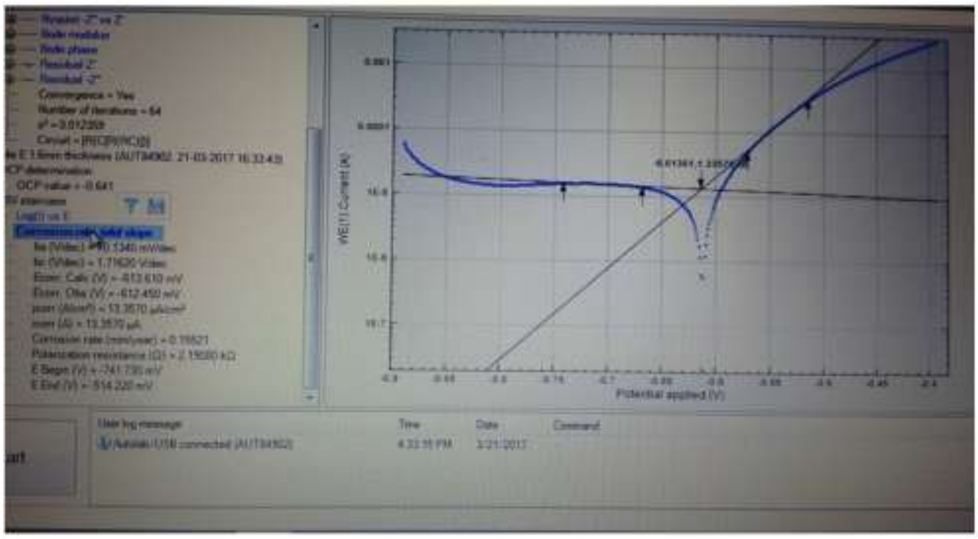

Figure. 5 Result of electrochemical studies

Table 1. Corrosion of cold formed steel sample in 3.5% Nacl solution

Sample number	Icorr µA	Ecorr calculated mv	Polorization resistance KΩ	ba mv /dec	Corrosion rate mm/y
CR1	23.62	-830.210	2.209	120.340	0.27450
CR2	22.149	-806.750	1.726	94.34	0.25562
CR3	20.241	-579.330	2.562	110.130	0.2331
CR4	17.320	-838.700	2.40	106.640	0.1990
CR5	16.650	-743.920	1.277	921.980	0.19218
CR6	13.357	-613.84	2.190	190.1340	0.15521

VII. Conclusion

The present paper reviews types of corrosion and theory behind corrosion. The Rate of corrosion varies from place to place like marine, rural and urban environments. From the coupon test it is noticed that rate of corrosion varies from minimum to a maximum value of 0.15521mm/y to 0.27450mm/y. It is seen that the variation in result is due to imperfections present on the coupons used to predict corrosion rate. From electrochemical study an average rate of corrosion is found to be 0.2194mm/y. As cold formed steel components are extensively used in modern life due to their lesser thickness and high strength to weight ratio. Due to lesser thickness rate of corrosion in these components is of prime importance. Therefore it is necessary to evaluate the corrosion rate in these components to predict the residual life of structural components.

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