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Prediction of Tensile strength and rate of corrosion in cold formed steel coupons

Manu.K.C[1], Cinitha.A[2], Palani.G.S[3], Kalappa.M.S[4], Jeevitha T.P[5]
[1]*Assistant professor, Department of Civil Engineering, Malnad College of Engineering, Hassan, Karnataka.*
[2]*Senior Scientist, CSIR-Structural Engineering Research Center, Chennai.*
[3]*Chief Scientist, CSIR-Structural Engineering Research Center, Chennai.*
[4]*Professor Department of Civil Engineering, Malnad College of Engineering, Hassan, Karnataka.*
[5]*Lecturer, Department of Civil Engineering, Smt LV Polythenic, Hassan, Karnataka.*
Corresponding Author: Manu.K.C1

Abstract: *Steel structures play a major role in structural components but one of the major problem faced by steel components is corrosion. Corrosion has increasingly become a structural problem world over which effectively reduces the weight and thickness of the components which finally reduces the strength of the steel structural components. In the present work cold formed steel members which are gaining more recognition compared to hot rolled steel as they are available in different thicknesses were used. Corrosion coupons, corroded and uncorroded tension coupons, of two different thicknesses 1.6mm and 3mm were used. The corrosion coupons are used to predict the rate of corrosion in a year. whereas in tension coupons the gauge portions were corroded for different percentages such as 15%, 30% and 45% and strength of corroded and uncorroded coupons were evaluated.*

Keywords: *Corrosion, steel components, Tension coupons, coupons*

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I. Introduction

Corrosion is a natural process which leads to a deterioration of steel structures. Most of the steel structures in India and different parts of the world are facing corrosion problem. The corrosion of metal occurs through electrochemical reaction at the interface between the metal and an electrolyte solution [5]. Due to corrosion load bearing capacity reduces, leading to failure of structures. Exposure of a steel structure to the aggressive humid environment (rich in chloride and sulphate content) and improper protection and maintenance causes corrosion [7]. To handle corrosion problem crores of money is invested, so it is necessary to predict the residual strength of existing structures in order to keep them in service. Corrosion wastage and stress concentration caused due to irregularity of the surface of the corroded steel influence the remaining strength of the corroded steel. Further, recent earthquakes have devasted steel corroded structures leading to failure. During the great Hanshin Earthquake of January 11,1995, many steel bridges suffered major damage. 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 [8]. A drastic reduction in mechanical properties such as yield and ultimate strength are observed for severely corroded members[10]. In addition, buckling, fracture and cracking in many steel structures were observed during Hanshin Earthquake. 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. Assessment of residual strength [12,14] and remaining resistance of a corroded structure is most important parameter as crores of rupees are lost every year owing to corrosion in various sectors. "The demand for corrosion free material is on the increase in high-end industries including oil and gas, energy and shipping, railways, ports etc, the Corrosion costs are reduced by effective application of available corrosion control technology. New and improved corrosion control technology results from research and development. As compared to hot rolled steel sections ,cold formed steel sections are less in weight and cross sectional shapes are formed to close tolerances , and these sections are widely used in construction and building industries now. Therefore the importance of the study of corrosion rate in cold formed steel, to evaluate the residual strength of the corroded components.

II. Materials and Methods

a) Cold formed steel coupons

In the present study cold formed steel coupons of size 3.5cm x 3.5cm with thickness 1.6mm were used to evaluate the corrosion rate. The sample was abraded using SIC coated abrasive paper of different grades, 220 to 1500; then using diamond paste to get a mirror finish and 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 performed in Autolab potentiostat and galvanostat (Nova 1.11) apparatus. Cold formed steel sample was embedded in an electrochemical cell which has an exposed area of 1cm^2. The prepared solution was poured in to the electrochemical cell. Three electrodes, counter electrode , reference electrode and working 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

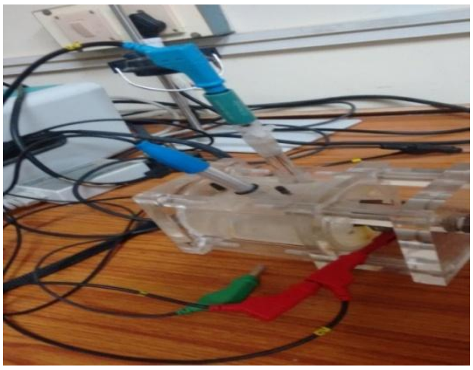

Fig 2(a): Electrochemical cell

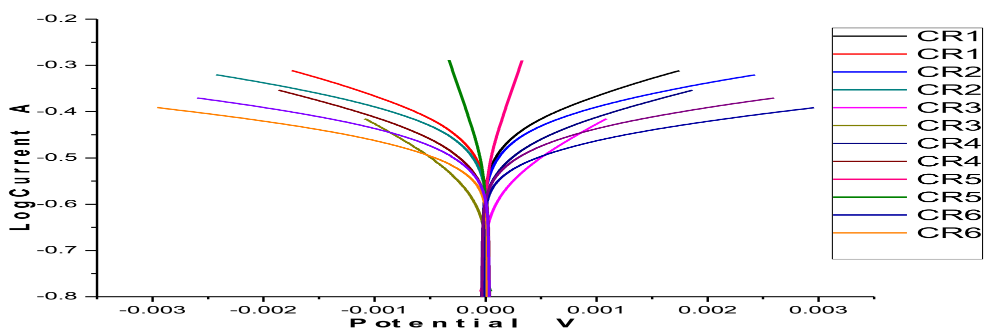

Fig. 3 Tafel plot for metal sample immersed in 3.5% Nacl solution

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. 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 0.140mm/y for sample number CC6 with polarization resistance of 2.234Ω and a maximum corrosion rate of 0.2574mm/y with polarization resistance of 2.02KΩ for sample CC5. On an average of 0.197mm/y corrosion rate is noticed.

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 with an increase in corrosion current from 12.233µA for sample number CC6 to 23.62µA for sample number CC5 . As corrosion current increases, increase in corrosion rate is noticed, in table 1.

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

Sample number	Polarization resistance(KΩ)	I_{corr}(µA)	E_{corr} (mv)	Corrosion rate mm/y
CC1	1.27	16.6520	-743.920	0.1921
CC2	2.40	17.320	-838.700	0.1990
CC3	2.56	20.241	-579.330	0.2330
CC4	1.66	13.947	-589.840	0.1620
CC5	2.02	23.62	-830.210	0.2574
CC6	2.24	12.233	-699.590	0.1410

b) Tension coupon

In the present work eight cold formed steel coupons with gauge length 57mm, gauge width 12.5mm, radius of fillet 12.5mm and grip 80mm on either side were used. The grip portion of each of the specimens was coated with inhibitor to prevent corrosion . The gauge portion of 57mm was corroded to the extent of 15%, 30% and 45% respectively by electrochemical method

Fig 4: Uncorroded coupon

The coupons 1.6UC and 3UC were used as uncorroded coupons and the remaining coupons were corroded for 15%, 30% and 45% respectively. The electrolyte solution was prepared by dissolving 35grams sodium chloride in 1000ml of deionized water. The tensile specimens were embedded in a plastic chamber such that the gauge portions comes in contact with the prepared solution. The tensile specimen was used as anode and another strip coupon extracted from same parent metal of size 60 x45mm was used as cathode which was placed at a distance of 35mm from the anode. Initial potential between anode and cathode was found out. Each specimen was weighed and then corroded for required percentage. Corroded sample was cleaned with brush and water and weighed. The percentage weight loss for each sample was calculated. The experiment was carried out by keeping current 2.5A as constant and by varying the voltage. The coupons were corroded to achieve a weight loss corresponding to the proposed percentage of corrosion. Uncorroded thickness and reduction in thickness of specimen after corrosion were measured at different locations using vernier callipers in order to determine the average thickness. Also width measurement was made in different corroded regions.

Fig 5: Corroded and uncorroded coupons with strain gauges

Fig 6: Corrosion – Experimental setup

c) Tensile Test

It is a material science test in which coupon sample was subjected to controlled tension until failure. The tests were conducted in universal Testing machine. Test was conducted on cold formed steel samples for obtaining the mechanical properties such as ultimate strength, young's modulus , Poisson's ratio, yield strength, maximum percentage elongation, percentage reduction in area were measured and strain hardening characteristics are calculated.

A tensile specimen has a standardized sample cross section. It has two shoulders and a gauge section in between. Shoulders are large so that it can be readily gripped, gauge section has smaller cross section so that deformation and failure will occur in this area. 5mm strain gauges were attached to the gauge section of the specimen in longitudinal direction of the specimen. The test was conducted using a testing machine with maximum load capacity of 500KN and the rate of loading was 0.01mm/s upto 0.2% strain and 0.1mm/s upto 0.5% strain until failure.

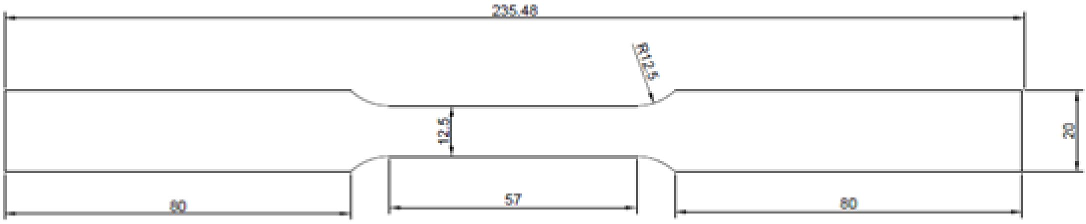

Fig 7: Dimension details of Tension coupon (mm)

Table 2. Specimen Details and Quantative Measure of Corrosion Coupons

Specimen no	Initial Weight(g)	Corrosion %	Current(A)	Time	Final weight(g)
1.6-15C	52.519	15	2.5	30min	51.158
1.6-30C	52.487	30	2.5	1h. 1min. 5sec	49.835
1.6-45C	52.509	45	2.5	1h.31min.1sec	48.709
3-15C	98.557	15	2.5	57min. 59sec	96.030
3-30C	98.507	30	2.5	1h.55min.55sec	93.577
3-45C	98.498	45	2.5	2h.53min.56sec	92.798

Fig 8: Tensile test

The tensile specimens of thicknesses 1.6mm and 3mm are corroded to 15%, 30% and 45%. A current of 2.5 A is and the percentage weight loss for all the samples were evaluated. The weight loss observed for all the samples are summarized in Table 2.

Calculation of Corrosion Rate from Corrosion Current

$$\mathbf{CR} = \frac{I_{corr}.K.EW}{dA}$$

where,
CR = the corrosion rate (mm/year)
Icorr = the corrosion current in amps
K = a constant that defines the units for the corrosion rate

EW = the equivalent weight in grams
d = density in grams/cm^3
A = sample area in cm^2

Based on thickness loss, the level of corrosion damage can be classified as

Mild Corrosion Level	$\mu > 0.75$
Moderate Corrosion Level	$0.75 \geq \mu \geq 0.5$
Severe Corrosion Level	$\mu < 0.75$

where, $\mu = \frac{t_{Avg}}{t_o}$

t_{Avg} = Average thickness of the corroded member
t_o = original thickness of the member
μ = Reduction in average thickness as a ratio

Table 3. Ultimate load of uncorroded and corroded specimens

Specimen name	original thickness (mm)	Final average thickness (mm)	Corrosion planned %	Actual corrosion	Corrosion Level	Maximum load(KN)
1.6UC	1.6	1.6	-	-	-	6.69
1.6-15C	1.6	1.49	15	15.20	Mild	5.29
1.6-30C	1.6	1.15	30	29.41	Moderate	4.45
1.6-45C	1.6	0.79	45	44.19	Severe	3.51
3UC	3	3	-	-	-	11.20
3-15C	3	2.90	15	14.46	Mild	9.57
3-30C	3	2.22	30	29.29	Moderate	7.81
3-45C	3	1.49	45	44.21	Severe	5.94

d) Stress –Strain Characteristics

The figure 9(a) and 9(b) A and A1 uncorroded samples. B and B1 for 15% corroded samples. C and C1 for 30% corroded samples. D and D1 are 45% corroded samples for 1.6mm and 3mm thickness respectively.

Tensile test was conducted using cold formed steel coupons to study the material characteristics. All the tension coupons were affixed with the strain gauges and the experiment was carried out to find the Stress-Strain behaviour of samples. The loads and strains were automatically recorded by an electronic data acquisition system. For uncorroded and corroded coupons ultimate strength and yield load was measured.

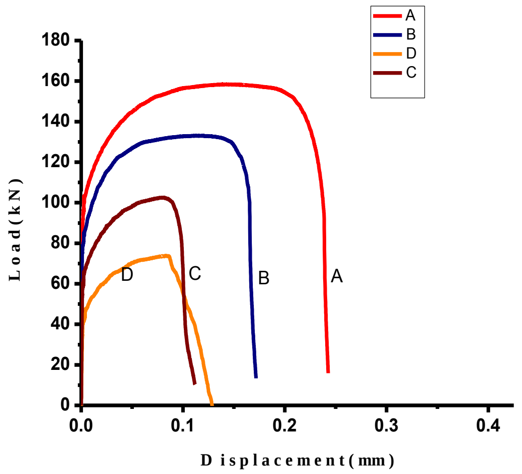

Fig: 9(a) 1.6mm thickness

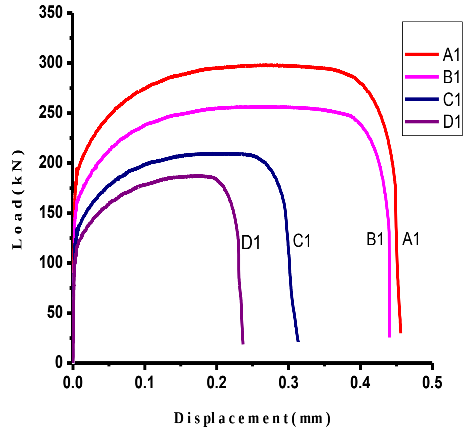

Fig: 9(b) 3mm thickness

Load displacement curves for tension coupon corresponding to 1.6mm and 3mm thickness coupons

Table 4. Ultimate load, Yield load and Percentage reduction in uncorroded and corroded specimens

Specimen name	Ultimate Load (N)	Percentage reduction in ultimate load	Yield Load (N)	Percentage reduction in yield load
1.6UC	158	-	105	-
1.6-15C	125	20.88	90	14.28
1.6-30C	100	36.70	70	33.33
1.6-45C	74	53.16	47.53	54.73
3UC	300	-	180	-
3-15C	248	17.33	160	11.11
3-30C	200	33.33	125	30.55
3-45C	175	41.66	100	44.44

III. Conclusion

1. From the electrochemical study for cold formed steel average corrosion rate of 0.197mm/y was observed.
2. Irregularities on the surface of corrosion coupon can lead to a false result in electrochemical corrosion testing as a result variation in corrosion rate was noticed.
3. From the study it is concluded that for both 1.6mm and 3mm thickness samples for 15% corrosion mild corrosion was noticed and for 30% corroded samples moderate corrosion was noticed and for 45% corroded samples severe corrosion was noticed.
4. Experimental study confirms that there is a drastic reduction in load carrying capacity for 45% corroded sample compared to uncorroded sample and it can be concluded that corrosion has major impact on failure of the specimen.
5. Increase in percentage of corrosion reduces ultimate strength and modifies mechanical properties of steel. Therefore prediction of residual strength in corroded specimens is important and a challenging task.

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