



WEIGHT LOSS ANALYSIS FOR LOW ALLOY STEEL IN SIMULATED CONCRETE PORE SOLUTION IN THE PRESENCE OF CHLORIDE

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ABSTRACT

Concrete corrosion generally refers to the deterioration of concrete due to various factors, which can compromise the integrity and longevity of structures. This deterioration often involves the corrosion of the reinforcing steel bars (rebar) within the concrete, leading to structural issues. TMT steel bars containing sufficient amount of corrosion reducing alloying elements such as chromium, copper and nickel are more suitable for uses in the coastal as well as industrial areas where corrosion of steel bars is a great concern.

Keywords:

Corrosion, reinforcement steel bar, weight loss.

I. Introduction

Corrosion of reinforced concrete structure is a major problem worldwide which is associated with the deterioration of reinforced concrete due to reaction of reinforcement steel bar in presence of concrete pore solution. Almost all components of infrastructure such as buildings, highways, airports, water supply, waste treatment, energy supply and power generation require significant investment and are subjected to degradation by corrosion, which significantly reduces the service life, safety, reliability, functionality of structures and equipment. This may result in damage of the structures due to expansion, cracking and eventually spalling of the concrete cover. In addition, the damage of construction may be caused by loss of bond between reinforcement and concrete and loss of reinforcement cross-sectional area. Corrosion of steel in concrete structures provides a comprehensive review of the subject, in addition to recent advances in research and technological developments from reinforcing materials to measurement techniques and modelling. Thus corrosion of reinforcing steel is now recognized as the major cause of degradation of concrete structures in many parts of the world. The extent of degradation depends on the severity of concrete pore solution resulted in not only the reduction in mechanical strength of the reinforcing bar itself, but also the expansion of the corrosion products. Despite all the precautions and preventive measures against corrosion, the infrastructure expenditure increased many folds due to degradation or deterioration of embedded steel in reinforced concrete structure.

In the present study the focus has been made on the corrosion of reinforced steel bar embedded in concrete structures and exposed to aggressive environments such as saturated concrete pore solution in which high concentration of chloride ions have been introduced. Also, the concentration has been given on the mechanism of chloride-induced corrosion of steel rebar in concrete through pore solution and its influence on the service life of RC structures. Many factors affecting the corrosion such as concentration of chloride ions, pH of the solution, process of chlorination and carbonation, time to corrosion initiation are described in details with regard to both concrete properties in pore solution and environmental exposure conditions. Many researchers reported that, corrosion of steel reinforcing bar is the major cause of premature failure of reinforced concrete structures worldwide, especially in chloride environments [1]. Corrosion prevention and durability of rebar is a critical issue and great challenge for the materials and corrosion engineer. Many efforts have been made by structural designers and materials engineers to prevent or minimize the degradation of embedded steel in concrete structures in presence of harsh conditions which affect the durability of the structures [2, 3]. As stated above; corrosion of steel rebar is the leading cause of deterioration in concrete. When steel corrodes, the resulting rust occupies a greater volume than the steel which exerted the pressure on



concrete. This expansion in volume of rust creates tensile stresses in the concrete, which can eventually cause cracking, delamination, and spalling.

Figure 1: Progression of sensors

II. Experimental

The reinforcement TMT rebars were cut into different sizes for studies. The chemical compositions of steel rebars were studied by optical emission spectroscopy. Steel rebars were cut by CNC Wire EDM machine. Different types of steel rebars were used to weight loss tests. As received steel rebars from two different producing companies were cut and pickled in 10 v/v % HCl, thoroughly washed with distilled water, dried and degreased with acetone. The steel rebars used in study were cut in cross section, abraded with emery paper starting from 100 to 1200 grits followed by cloth polishing with 5 μm alumina paste. Two different solutions were used in this study. Firstly, a solution of sodium hydroxide (NaOH) = 8.33g/L + potassium hydroxide (KOH) = 3.36g/L + calcium oxide (CaO) = 2.0 g/L was used to emulate the fresh concrete pore solution. For the preparation of second solution an amount of 35g/L NaCl was mixed in the prepared Simulated Concrete Pore solution for achieving the aggressiveness of the electrolyte.

Table:1 Chemical composition of used specimen in weight %

Sample	C	Si	Mn	P	S	Cr	Cu	Ni	Sn	As	Fe
Steel [S]	0.264	0.199	0.79	0.037	0.037	0.051	0.017	0.027	0.014	0.016	98.804
Steel [T]	0.238	0.179	0.73	0.016	0.023	0.010	0.003	0.048	<0.001	0.006	98.980

Weight Loss Tests

Weight loss tests are a very widely used corrosion measurement and monitoring technique. They are simple to understand and provide a direct measure of corrosion rate, allow a direct comparison of the relative resistance to corrosion of one sample with another under comparable or standard conditions, and provide a sound basis for estimating the likely active life of process equipment. There are numerous standard techniques for weight loss testing [4, 5].

The samples for these tests are called coupons and may have one of a given number of geometries (usually a small flat rectangular sheet or cylinder). The samples are surface finished, and the surface area determined. Care should be taken to avoid cross-contamination and for example, new polishing paper should be used to avoid contamination of the metal surface. The coupon is degreased (washed in a suitable solvent) after which it should not be touched directly, dried and accurately weighed. The coupon should then be exposed to the corrosive environment of interest. If the sample is to be stored it should be kept in a desiccator. The weight loss technique involves exposing a specimen or coupons of material to the corroding environment for a given duration and then removing the specimen for weighing is the best known and the simplest of all corrosion measurement techniques. The weight loss or gain is taken over the period of exposure and later expressed as a corrosion rate. The determination of weight loss of a material in a corrosion experiment has been one of the common methods used to calculate corrosion rates. The weight loss technique is used so as to enable the corrosion rate measurements to be done without disturbing the plant operation. The advantage of the weight loss technique is that the corrosion which has actually occurred can be observed on the sample. Moreover, this technique allows a visual examination, physical measurements and the chemical analysis of the corrosion products.

Following its immersion in the test solution, a sample should be closely inspected for, e.g. visual signs of localised attacks such as pitting or deposits which can help identify the causes of corrosion. Next, any corrosion products adhering to the sample should be removed from the surface to allow accurate determination of corrosion weight loss. Cleaning methods are either mechanical (scraping or brushing)

or chemical (using solvents). Chemical cleaning is generally preferable, but the solution used will be specific to the metal being cleaned. Normally, the sample undergoes a number of equivalent cleaning cycles with the sample being weighed after each one. Mass loss is plotted against the number of cleaning cycles [6].

Corrosion coupons can be mounted in different configurations to study different types of corrosion mechanisms, such as crevice corrosion, galvanic attack and stress corrosion. Coupons, which are test specimens of the material of interest, are carefully cleaned, weighed and measured before being assembled on the corrosion test probes [7]. During assembly, the coupons are arranged such that they are electrically insulated from the corrosion probe so as to avoid galvanic attack. After a prescribed period of exposure, the corrosion probe is disassembled and the corrosion coupons are chemically cleansed, weighed and measured. Assuming uniform corrosion takes place over the entire surface of the coupon, the corrosion rate is calculated from the weight loss, time of exposure and original exposed surface area of the material by the following formula [8]:

$$MPY = 534 W / DAT$$

Where MPY is mil per year, W is weight loss (mg), A is area of specimen (in²), T is exposure time (hr), D is density of specimen (g/cm³). Corrosion rate can be expressed in millimetres per year (mm/y), mils per year (mpy) or milligrams per square centimetre per day (mg/cm²d)[9].

**Weight loss analysis
In SPS solution**

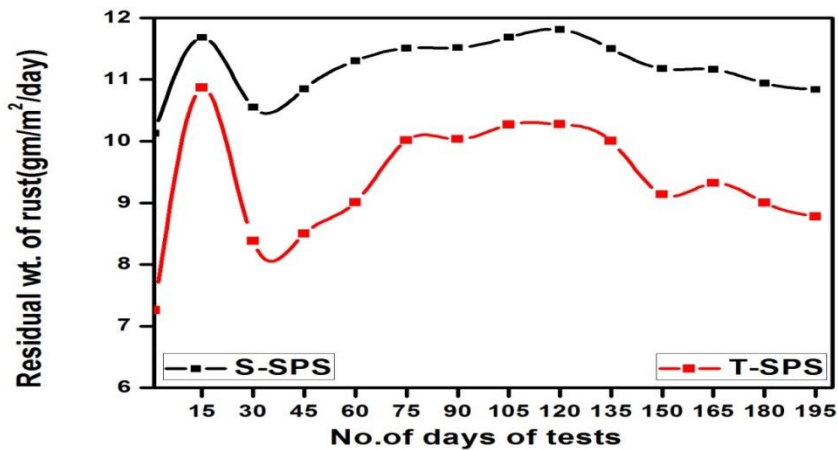


Figure.1: Retention of rust on Steel -S and T wetted with pH 12.5 solutions and exposed in laboratory environment.

In SPS + 3.5 %NaCl solution

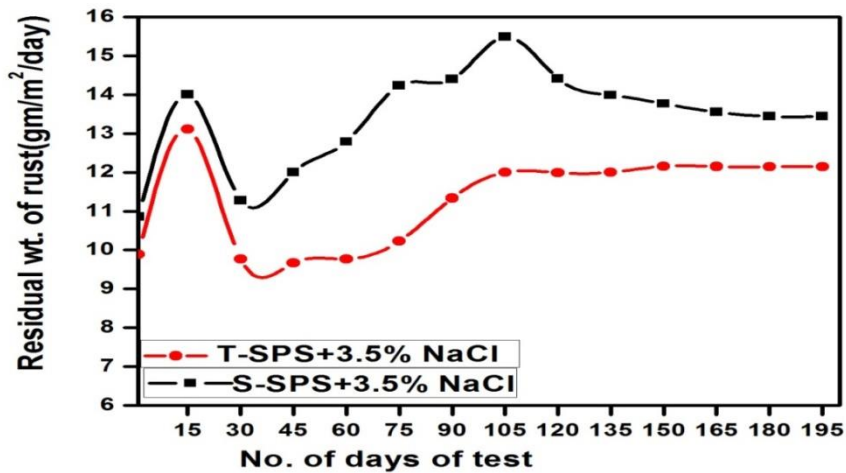


Figure.2: Retention of rust on Steel -S and T wetted with pH 11.45 solutions and exposed in laboratory environment.

$$\text{Corrosion rate, } CR = \frac{87.6 \times W}{DAT} \text{ mm / y}$$

Where, W is the weight-loss (mg), D is the density (g/cm³), A is the area (cm²) and T is the time of exposure (hr.).

D=7.86 g/cm³, A=2.0 cm², T=3600 hr.

(a) In SPS solution

Steel T, Corrosion Rate =0.600284 mm/yr., Steel S, Corrosion Rate =0.5991999 mm/yr.

(b) In SPS + 3.5 %NaCl solution

Steel T, Corrosion Rate =1.493433 mm/yr., Steel S, Corrosion Rate =0.88928 mm/yr.

It is seen from Figure that the rust formed on two steel rebars at pH of 11.45 exhibit considerable differences on their adherence behaviour. The residual rust on surface of Steel S is higher in comparison to Steel T during all period of tests. After an exposure of 195 days, the Steel T exhibits a decline in weight of rust indicating that the oxide formed on its surface falls off during cleaning by brush before recording of the weight. In case of Steel S, however, the gain in weight gets stabilized beyond this period and ultimately comes down due to slower rusting at the oxide–metal interface. The trend in retention of weight of rust at pH of 12.50 on steels’ surface with passage of time is more or less the same as noted for pH of 11.45. The only difference is in rust retention tendency after exposure of 195 days. In this case, both Steel T and Steel S steels exhibit a decrease in residual weight of rust/unit time. It is to be noted here that this decrease is not due to falling of the loose rust rather due to slow rate of rusting. This may be due to change in structure and morphology of rusts formed on two steels as result of increase in pH of the solution. The results plotted in Figure for this pH electrolyte show that the adherence of rust for Steel S is appreciably higher at all duration of exposures.

A careful examination of the plots reveal that at pH 11.45 and 12.50, the ratio of rust retained for Steel S and Steel T remains in the range of about 5. This suggests that the rust on Steel S at higher pH solutions forms very stable structure and develops impervious morphology, irrespective of the presence of chloride. The findings of this investigation may have important implications especially where the choices of use of steel rebars are to be considered in high alkali SPS solution. The adherence of rust to the surface of steels should affect their ultimate corrosion rate. The specimens after completion of the experiments were cleaned in Clarke [9] solution as recommended in ASTM G1 90 [10] to determine their loss in weight. Steel S is observed to corrode slower rate than the Steel T. This suggests that a rebar rolled from Steel S would considerably withstand the corrosion caused by saline



contaminated concrete provided its pH remains intact (>12.50). In other words, in coastal areas having little polluting gases, Steel S rebars should perform for better than Steel T rebars.

III Conclusions

It is observed from the experimental results that in presence of chloride ions, the corrosion rate of both the steel increases. However, both the steel corrodes in a significantly slower rate than that of the corresponding to conventional steel bars. TMT steel bars containing sufficient amount of corrosion reducing alloying elements such as chromium, copper and nickel are more suitable for uses in the coastal as well as industrial areas where corrosion of steel bars is a great concern.

From the weight loss results showed that curve of steel (S-SPS) is more in comparison to steel (sample T-SPS) in simulated concrete pore solution and simulated concrete pore solution with addition of 3.5% NaCl. This indicates that steel (sample S-SPS) has more corrosion resistance in comparison to steel (sample T-SPS)

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