# Evaluation of the Corrosion Resistance of Reinforcement Steel Rod in NMDC Borehole Water

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## Abstract

Evaluation of the corrosion resistance of reinforcement steel rod in NMDC Borehole water has been carried out. The work analysed the composition of the steel specimen used using spectrolab. The specimens were prepared into identical 10mm x 10mm specimens using specimen lathe. They were then washed in acetone and rinsed in tap water before drying using hand air blower. The specimens were then weighed and initial dimensions were taken using digital weighing balance and vernier caliper respectively. The specimens were immediately immersed in the medium which was a flat-bottomed flask, filled with water from NMDC borehole up to 250ml. The specimens were exposed for 5 weeks. For every week one specimen was removed, washed and brushed thoroughly and then dried and weighed. The variation of the pH of the medium was also measured every week. The data collected was used to determine the weight loss, percentage weight loss, pH variation of the medium, and to calculate the corrosion rate in mpy. The result of the analysis indicated that the steel rod was a low carbon steel with carbon content of 0. 304% C. The weight loss of the specimens for the 5 weeks was, 0, 20mg, -30 mg, 10mg, 20mg, 60mg starting from the first day to the last day. The -30 mg indicated the formation of a tenacious film on the steel. The highest percent weight loss of 0.84% occurred at the exposure time of 840 hours; this also corresponded to the highest pH of 9.37. The corrosion rate exhibited an active-passive-transactive pattern for the 5 weeks of exposure time. The corrosion rate was 11.16 mpy at 168 hours of exposure. The corrosion rate then experienced retardation and then increased again at 840 hours of exposure to 6.70 mpy. The corrosion rate of usefully resistant materials generally range between 1 and 200 mpy; the DSC reinforcement steel rod is therefore a material that can be used in this medium more so that it is going to be embedded in concrete casting. It is however advisable that the concrete should be uniform so as to reduce penetration of oxygen as much as possible.

***Keywords***: Evaluation, Low carbon steel, Reinforcement rod, Corrosion, Resistance, Borehole water.

## 1. INTRODUCTION

Evaluation of the properties of a material before application of the material is very important. In Nigeria today the country has witnessed so many incidences of collapsed building. This has lead to several ongoing research works on the various brands of reinforcement rods available in the market [1],[2]. In a research work on the characterization of reinforcement steel rods in the Nigerian market Onyeji, [2] discovered a compositional problem. Most of the steel rods did not meet the chemical specification for reinforcement rods for building structures. In another research work carried out at NMDC Jos on reinforcement rods which were sampled from a collapse structure; the researchers also discovered that the materials failed to meet the mechanical properties specified for reinforcement rods [1]. However, not much has been done to investigate the effect of corrosion on the reinforcement rods which is equally important when considering failure of a material. Corrosion as defined by Ihom,[3] is the destruction or deterioration of a material because of reaction with its environment. According to him not only ferrous materials corrode but other materials also possess varying degrees of instability. Thus rubber 'perishes' particularly when exposed to air and sunlight, and some plastic materials become progressively more brittle under the influence of ultra-violet light. He further stressed in his work that concrete and other ceramic materials are gradually eroded by frost and the chemical effects of our polluted atmosphere. A large group of materials both metallic and non-metallic may be damaged to some degree by various forms of radiation. From the foregoing the argument of several researchers that imbedded reinforcement steel rods are excluded from corrosion is not absolute. Apart from the concrete eroding and exposing the reinforcement steel rod; the reinforcement steel rods can be exposed as a result of poor casting or filling of the concrete mixture. What then becomes of the exposed steel rods? Definitely corrosion will not just look at it like that when the water is there, dissolve oxygen is also there [4],[7].

Corrosion is an electrochemical process which has two reactions: oxidation (anodic reaction) and reduction (cathodic reaction). An oxidation or anodic reaction is indicated by an increase in valence or a production of electrons. A decrease in valence charge or the consumption of electrons signifies a reduction or cathodic reaction. Oxidation and reduction are partial reactions-both must occur simultaneously and at the same rate on the actual surface. If this were not true, the metal would spontaneously become electrically charged, which is clearly impossible. This leads to one of the most important basic principles of corrosion: during metallic corrosion, the rate of oxidation equals the rate of reduction in terms of electron production and consumption). In some corrosion reactions the oxidation reaction occurs uniformly on the surface while in other cases it is localized and occurs at specific areas. Partial reaction equations can be used to interpret virtually all corrosion problems. When iron or steel is immersed in water which is exposed to the atmosphere, (reinforcement steel rod for example) corrosion occurs [8],[9]. The anodic reaction is:

$$Fe \longrightarrow Fe^{2+} + 2e \quad (1)$$

Since the medium is exposed to the atmosphere, it contains dissolved oxygen. Water is nearly neutral, and thus the cathodic reaction is:

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

The overall reaction can be obtained by adding 1 and 2:

$$2Fe + 2H_2O + O_2 \longrightarrow 2Fe^{2+} + 4OH^- \longrightarrow 2Fe(OH)_2 \quad (3)$$

Ferrous hydroxide precipitates from solution. However, this compound is unstable in oxygenated solutions and is oxidized to the ferric salt:

$$2Fe(OH)_2 + H_2O + 1/2O_2 \longrightarrow 2Fe(OH)_3 \quad (4)$$

The final product is the familiar rust. Iron will not corrode in air-free water because there is no cathodic reaction possible. Very pure water is much less corrosive than impure or natural waters. The low corrosivity of high –purity water is primarily due to its high electrical resistance [8],[9].

The objective of this paper is to evaluate the corrosion behavior of reinforcing steel rod in NMDC borehole water. This water is used for concrete mixing in NMDC. It is also the water contained in the soil where NMDC structures are standing.

## 2 MATERIALS AND METHODS

### 2.1 Materials/Apparatus

The materials used for the work were reinforcement rod obtained from Delta Steel Company, Aladja, NMDC Borehole water, tap water, acetone, and distilled water.

The apparatus used for the work included, pH meter, flat-bottomed flasks, suspension rail and thread, specimen lathe, vernier calipers, brush, No.120 abrasive paper, hand air blower, and digital weighing balance.

### 2.2 Methods

The 10mm diameter reinforcement rod used was obtained from Delta Steel Company, Aladja an integrated steel company in Nigeria. The chemical composition of the steel specimen was determined using spectrolab in the analytical services laboratory of NMDC Jos. To evaluate the corrosion resistance and behavior of the composite, samples of the steel rod were cut and prepared into test coupons or specimens using specimen lathe. The specimens were machined into identical 10mm x 10mm specimens. No.120 abrasive paper was used to smoothen the specimens. The specimens were then measured again using a vernier caliper to establish the initial dimensions of the specimens for calculation of the initial surface area of the specimens. After measuring, the specimens were degreased by washing in acetone, dried and weighed using a digital weighing balance to 2 decimal places or the nearest 0.1 mg. The specimens were dried using a hand air blower. The specimens were then immediately exposed to NMDC Borehole water in a 250ml flat-bottomed flask for the evaluation of the corrosion resistance of the mild steel in the media. The specimens were checked every Thursday, since the experiment was set up on a Thursday. The specimens were given numbers 1-5 and were removed according to their number. On every Thursday of every week, one specimen was removed from the medium, washed under tap water and scrubbed using brush. After washing the specimen was dried using hand air blower. It was then weighed using a digital weighing balance and the result recorded. This was done for five weeks. The pH of the medium was measured using a pH meter. The method of measurement and equipment used both conformed to JIS Standard [10]. When the medium was prepared, and each time a specimen was removed for weighing, the pH of the medium was also measured. pH measurements were taken for five weeks (see plate 1). The minimum exposure time for the experiment was determined from the formula:

Hours (duration of test) = 2000/ mils per year (1)

The data generated from the experiment was used to calculate the weight loss, the percentage weight loss, the corrosion rate in mils per year, and also to record the pH variation of the media over the 5 weeks. Precautions taken during the experiment were: care was taken not to contaminate the specimen or alter them during specimen preparation, initial measurements were taken, fixed time was kept for weighing of specimens, during washing care was taken to avoid over scrubbing, and a specimen was provided for every week once the specimen was taken out for weighing, it was not returned back to the medium. These precautions were taken for reliable results to be generated.

**Plate 1: Testing of the medium using pH meter**

## 3 RESULTS AND DISCUSSION

### 3.1 Results

The results of the work are as presented in Tables 1- 2, Plate 2 and Figure 1.

### 3.2 Discussion

Table 1 shows the composition of the reinforcement rod produced by Delta Steel Company, Aladja an integrated steel company in Nigeria. The percent carbon is 0.304, which makes it a low carbon steel. The presence of the other elements can be traced to the raw material used for the production of the steel which is 100% scraps using the electric arc furnace process. Table 2 shows the weight loss values, percent weight loss and pH Variation of the NMDC Borehole water at the various exposure times of the specimens. At the beginning when the specimens were prepared the weight loss was zero, the measured pH of the medium was 6.98. When the specimen was exposed for 168 hours the weight loss rose to 20mg the percent weight loss was 0.28 and the pH of the medium increased to 8.55 making the medium to become alkaline. This also an indication that corrosion took place and the steel went into solution. A similar observation was made by Oki [9] that the pH of the medium changes as steel corrodes in water. As the exposure time increased to 336 hours the weight loss read negative 30mg indicating that there was a weight gain as a result of the formation of corrosion film which the scrubbing and washing did not remove the weight loss corresponded to a percentage weight loss of negative 0.41. The pH however dropped to 7.70 slightly alkaline. When the exposure time increased to 504 hours the weight loss became 10mg which corresponded to 0.14 percent weight loss and the pH of the medium still dropped to 7.68. When the exposure time increased to 672 hours the weight loss increased to 20mg corresponding to percent weight loss of 0.28. The pH also increased to 9.29; the increase in alkalinity confirms the weight loss. At the final exposure time of 840 hours the weight loss increased further to 60mg and the percent weight loss increased to 0.84 this was confirmed by the pH which increased to 9.37 indicating that more of the steel has gone into solution as a result of corrosion. Some researchers have observed that corrosivity of fresh water varies depending on oxygen content, hardness, chloride content, sulphur content and many other factors [8],[12]. The medium was exposed and dissolved oxygen must have contributed to the increased weight loss observed.

Plate 2 shows the specimens after exposure at various periods in the medium the brownish coloration on the surface of the specimens increased with exposure time of the specimens. The weight loss was however not conspicuous by mere physical examination of the specimens.

Figure 1 shows the corrosion rate in mpy of DSC reinforcement steel rod exposed in NMDC Borehole water for 5 weeks. The figure showed the corrosion rate increasing to 11.16 mpy at the exposure time of 168 hours. At the exposure time of 336 hours the corrosion rate showed a negative value of 8.38. The specimen at this point formed a corrosion film which was not removed, despite the washing and scrubbing: this resulted in weight increase which gave the negative corrosion rate. The corrosion rate then continued to drop, and it dropped to 2.79 mpy at 672 hours after which it increased to 6.70 at 840 hours. This behavior is common with steels and has to do with the nature of corrosion films formed on the surface of the steel. As explained earlier under introduction when steel is immersed in water which is exposed to the atmosphere corrosion occurs. The iron goes into solution as shown in equation (i) above. Since the medium is exposed to the atmosphere, it contains dissolved oxygen. Water is nearly neutral, and thus the cathodic reaction is as shown in equation (2) above. The overall reaction leads to the formation of ferrous hydroxide precipitates from solution. However, this compound is unstable in oxygenated solutions and is oxidized to the ferric salt, see equations 3 and 4. The final product is the familiar rust which was seen on the specimens [8],[13]. This explanation also explains why the pH of the medium was varying. The corrosion rate can best be explained in terms of passivity and nature of corrosion coatings or films. Within the first 168 hours, corrosion of the steel was taking place, at the same time the thickness of the film was increasing. As the exposure time increased the film became thicker and more uniform, this led to the slowing down of the corrosion rate until the film got broken and the barrier was removed. This can be seen at 840 hours; the corrosion rate again shoots up to 6.70 mpy. This is typical of steel which exhibit active-passive-transpassive behavior [8], [15].The corrosion rate of usefully resistant materials generally range between 1 and 200 mpy; the DSC reinforcement steel rod is therefore a material that can be used in this medium more so that it is going to be embedded in concrete casting. It is however advisable that the concrete should be uniform so as to exclude oxygen as much as possible.

## 3 CONCLUSION

Evaluation of the corrosion resistance of DSC reinforcement steel rod in NMDC Borehole water has been carried out and the following conclusions drawn:

- Within the exposure time of the experiment the result has shown that the corrosion rate of the DSC reinforcement rod is within the range of 1 to 200 mpy for usefully resistant materials.
- The reinforcement rod has exhibited active-passive-transpassive behavior, there is therefore need to ensure that when using it the concrete work should be sound to exclude oxygen as much as possible to reduce the corrosion rate of the steel. This will reduce the incidence of collapse structures and buildings.

**TABLE 1**

**CHEMICAL COMPOSITION OF THE REINFORCEMENT STEEL ROD USED FOR THE CORROSION TEST**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Element** | C | Si | Mn | P | S | Cr | Ni | Mo | Al |
| **%** | 0.304 | 0.173 | 0.61 | 0.029 | 0.024 | 0.027 | 0.0085 | <0.0020 | 0.012 |
| | | | | | | | | | |
| **Element** | Cu | Co | Ti | Nb | V | W | Pb | B | Sn |
| **%** | 0.026 | 0.0076 | 0.0010 | <0.0030 | 0.0047 | .018 | <0.0030 | <0.005 | <0.0010 |
| | | | | | | | | | |
| **Element** | Zn | As | Bi | Ca | Ce | Zr | La | Fe | |
| **%** | 0.012 | 0.0043 | <0.0020 | 0.0099 | 0.0041 | <0.0015 | 0.0066 | 98.7 | |

**TABLE 2**

**WEIGHT LOSS OF DELTA STEEL COMPANY REINFORCEMENT STEEL ROD EXPOSED IN NMDC BOREHOLE WATER FOR FIVE (5) WEEKS AND THE PH VARIATION OF THE MEDIUM**

| S/no. | Exposure Time Hours | wt. Loss (mg) | % wt. Loss | Ph |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 6.98 |
| 2 | 168 | 20 | 0.28 | 8.55 |
| 3 | 336 | -30 | -0.41 | 7.70 |
| 4 | 504 | 10 | 0.14 | 7.68 |
| 5 | 672 | 20 | 0.28 | 9.29 |
| 6 | 840 | 60 | 0.84 | 9.37 |


**Plate 2: Shows the Specimens after Exposure in the NMDC Borehole Water at Various Exposure Periods.**

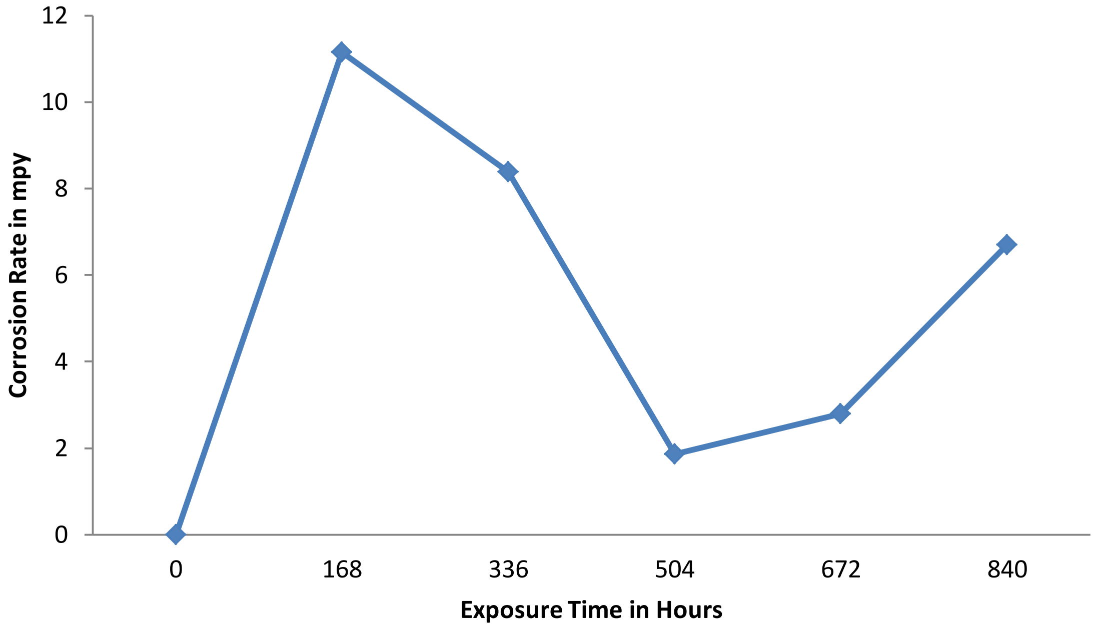


**Fig. 1. Corrosion Rate in mpy of DSC Mild Steel Reinforcement Rod in NMDC Borehole Water.**

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