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Research article

EVALUATING THE CORROSIVITY OF RAINFALL EXPOSED STEEL BAR IN HCl, NaOH AND NaCl SOLUTIONS.

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Abstract

The corrosion behavior of rainfall exposed steel bar in 1M acid, 1M alkaline and 1M salt solutions had been studied. The exposed and unexposed coupons were immersed in the media for thirty days, at 25^oC–32^oC. Using weight loss method, the acid corrosion of exposed and unexposed bars in 1M HCl was 0.55 to 0.27 MPY and 0.71 to 0.38 MPY respectively. The alkaline corrosion was same (7.8×10^{-4} to 1.29×10^{-4} MPY) in NaOH solution. The corrosion rate of both bars in 1M NaCl solution was respectively 4.65×10^{-3} to 3.88×10^{-3} MPY and 3.1×10^{-3} to 3.23×10^{-3} MPY.

Keywords: Steel, Acid solution, Weight loss, Acid corrosion, Alkaline corrosion

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Introduction

Corrosion is generally classified according to the visual appearance of the corroded surface. It takes many forms depending on the metal, the environment involved and the process by which the damage is created [1]. Not all materials have the ability to resist the attack of the environment in which they find themselves. They may be resistant in one environment, while the opposite may be the case in another environment [2]. The most common method of preventing corrosion is the selection of the proper metal or alloy for a particular corrosive service, since this is the most important method of preventing or reducing corrosion damage [3].

Iron and Steel are the most versatile, least expensive and most widely applied of the engineering materials. Their main disadvantage is that iron and most alloys based on it have poor resistance to corrosion in even relatively mild service environments [4]. This generalization includes reinforcing steel bars, in which carbon is the main element which governs the properties of the steel. Carbon in itself has little if any effect on general corrosion resistance of steels in most cases [3].

In general, unpolluted rainwater has a pH of less than 6, which is slightly acidic. This is due to naturally occurring carbon dioxide in the atmosphere reacting with the water vapour to lower the pH [5]. Rain is one of the natural waters that are near neutral aqueous media approaching equilibrium with the atmosphere, in which the absorption of oxygen is the dominant cathodic reaction. The oxygen potentials in these environments are close to the equilibrium line for oxygen absorption on the iron-water pourbaix diagram. However, the approach by electrochemical partial reactions at the metal surface place the corrosion potential in the domain of stability for Fe^{2+}, so that the primary products are produced by the anodic dissolution of iron:

$$Fe = Fe^{2+} + 2e^{-} \qquad (1)$$

Complimented by the cathodic absorption of oxygen:

$$1/2O_2 + H_2O + 2e^{-} = 2OH^{-} \qquad (2)$$

When the concentrations of Fe^{2+} and OH^{-} ions close to the metal surface exceed the low solubility product, the first solid product, $Fe(OH)_2$, is produced:

$$2Fe^{2+} + 6OH^{-} = 2Fe(OH)_2 \qquad (3)$$

The initial deposit of $Fe(OH)_2$ is only the provisional corrosion product and it is slowly oxidized to compositions approaching that of the stable iron(III) hydrous phase. It is also reported that $Fe(OH)_2$ deposit obstructs diffusion of oxygen to the metal surface but lacks the coherence needed to protect iron [4]. Corrosion products (rusts) may act as a barrier between the metal and its surroundings, slowing down the corrosion rate. In some cases this barrier very effectively retards corrosion. This is called passivation, which increases the corrosion resistance of metal remarkably [6]. Townsend has reported the corrosion resistance of weathering steels due to adherent, protective rust layer formed during outdoor exposure [7].

It has been observed that at many construction sites, reinforced steel bars are left exposed to the elements for long periods of time before being put to use. Hence, this research is aimed at studying the corrosion characteristics of rainfall exposed reinforced steel bar in 1M HCl, 1M NaOH and 1M NaCl solutions.

Materials and methods

Materials

The steel bar used in this research was sourced from commercial steel vendor and its chemical composition was determined at the analytical department of National Metallurgical Development Centre, Jos, Nigeria, as shown in Table 1. Other materials used included; 1M hydrochloric acid (HCl), 1M caustic soda (NaOH), 1M sodium chloride (NaCl), ethanol and distilled water.

Methods

The steel bar was cut into corrosion coupons (Cylindrical shape) of dimension 1 cm × 1 cm for exposure to rainfall. 18 coupons were exposed for 5 months, after which they were subjected to corrosion test comparatively to fresh cut coupons of the same number, size and shape from the reinforced steel bar.

Corrosion Testing

18 exposed reinforced steel bar coupons and that of unexposed were produced for 1M HCl, 1M NaOH and 1M NaCl solutions. The coupons were weighed and stored in dessicator. 1M HCl, 1M NaOH and 1M NaCl solutions were prepared and the coupons immersed in these solutions. The weight loss of each coupon was determined at 5 days interval for 30 days. Then the rate of corrosion in each solution was determined. The experiment was conducted at room temperature in the range of $25^oC – 32^oC$ [8].

Determination of Corrosion Rate (MPY)

Corrosion rate was determined using the weight – loss method. The weight loss was obtained by finding the difference between initial and final weight of coupon after 5 days of immersion from the relationships [3]

$$W = W_o – W_f \qquad (4)$$

Where W – weight loss after 5 days,

W_o – initial weight

W_f – final weight

The standard expression for measurement of corrosion rate in Mils per Year (MPY) was used which is given as follows [3] and [9]:

$$MPY = 534W/DAT$$

Where MPY – mils per year, W – weight loss in mg, D – density of the materials in g/cc, T – time of exposure in hours, A – area in in^2.

Results and Discussion

Results

The chemical compositions of the steel bar is presented in Table 1, while Figures 1, 2, and 3 show the variation of corrosion rates with time of exposure for exposed and unexposed steel bar in 1M HCl, 1M NaOH and 1M NaCl solutions respectively.

Table 1: Chemical Composition of the Steel Bar

C %	Si %	Mn %	P %	S %	Cr %	Ni %	Mo %	Al %	Cu %
0.306	0.172	0.6	0.029	0.024	0.027	0.0085	0.002	0.012	0.026
Co %	Ti %	Nb %	V %	W %	Pb %	B %	Sn %	Zn %	As %
0.0076	0.001	0.0030	0.0047	0.018	0.0030	0.005	0.001	0.012	0.0043

Bi %	Ca %	Ce %	Zr %	La %	Fe %				
0.0020	0.0099	0.0041	0.0015	0.0066	98.7				

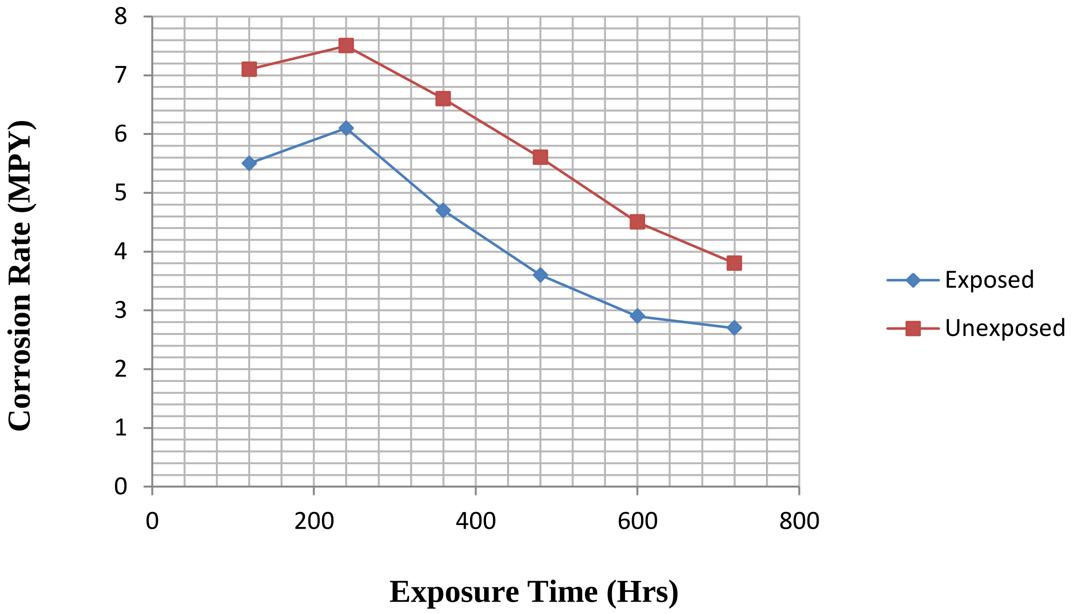

Figure 1: Variation of corrosion rate with time of exposure for exposed and unexposed steel bar in 1M HCl solution

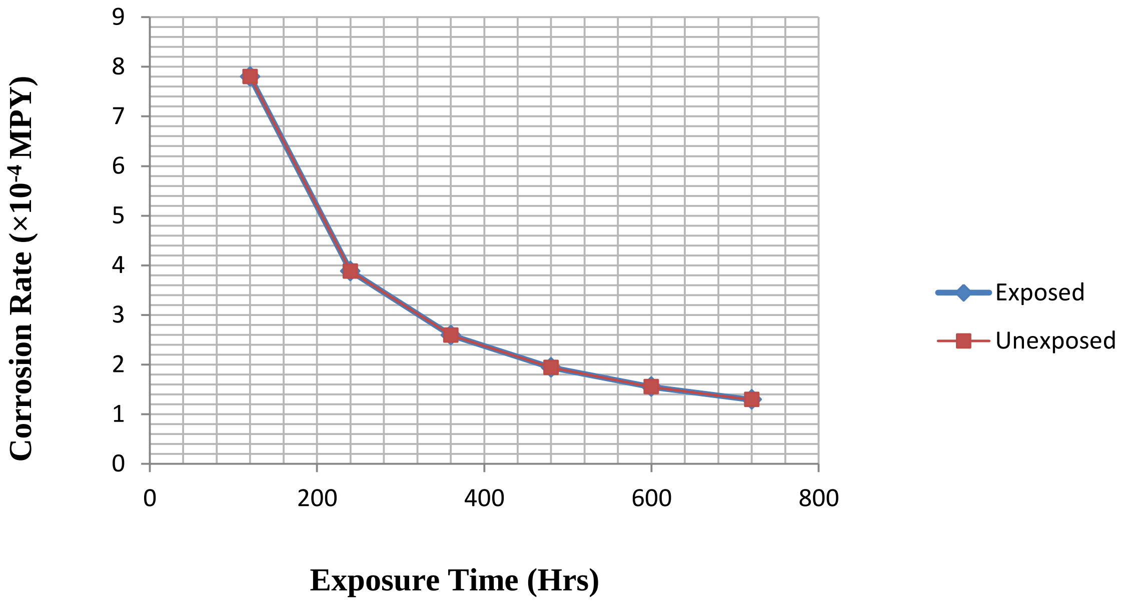

Figure 2: Variation of corrosion rate with time of exposure for exposed and unexposed steel bar in 1M NaOH solution

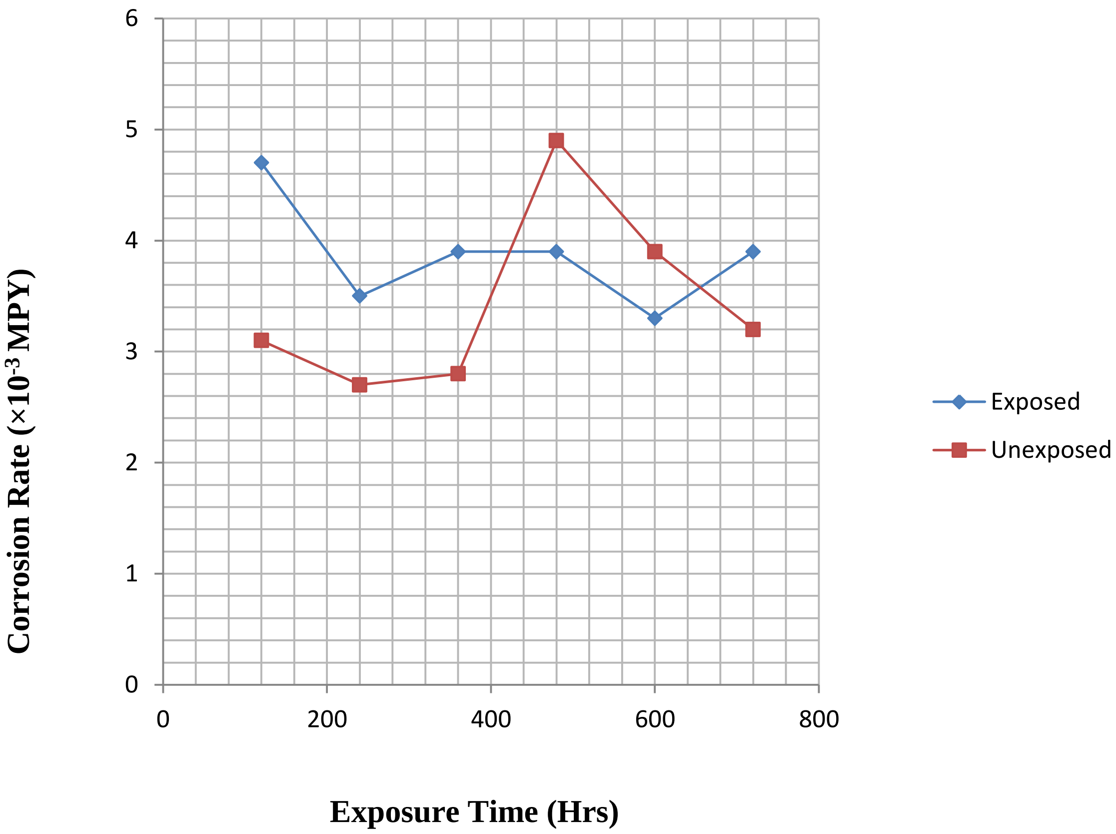

Figure 3: Variation of corrosion rate with time for exposure of exposed and unexposed steel bar in 1M NaCl solution

Discussion of results

Visual observation of the coupons

Visual observation of exposed and unexposed steel bar coupons in the solutions of 1M HCl and 1M NaCl after 30 days (720 hours) of immersion revealed changes in colour of the coupons from initial bright dark grey surface to rusty, while the colour of the coupons in 1M NaOH changes from initial bright grey surface to dull ones. Cracks and pits were observed on the surface of the coupons in 1M HCl and 1M NaCl solutions which are indication of severe corrosion attack by the acid and salt solutions. Although, the change in colour and presence of cracks and pits were more noticed on the unexposed coupons in the acid solution. No cracks or pits were visible to naked eyes on the surface of the coupons in 1M NaOH after 30 days, which indicates that the coupons were not really attacked in the alkaline solution.

Corrosion rate analysis

The results obtained on the corrosion rate against exposure time for exposed and unexposed reinforcing steel bar coupons in 1M HCl solution plotted in Figure 1; it clearly shows that corrosion rate increased with time from 0.55 to 0.61 MPY for the first ten days due to initial corrosion attack and subsequently decreased from 0.61 to 2.7 MPY after thirty days probably due to the deposition of corrosion products as the corrosion progresses which tends to shield the corroding surface from further corrosion attack, thereby depressing the rate of corrosion [3]. The corrosion rate of exposed coupons were lower (as can be seen by the position of the plot which is lower) than that of unexposed ones due to adherent, protective rusty layer formed during outdoor exposure [7].

Figure 2 was able to express the corrosion of the coupons in NaOH solution; it is clear that corrosion decreased with time from 7.8×10^{-4} to 1.29×10^{-4} MPY for the exposed and unexposed coupons in solution after thirty days probably due to passivity of the surface of the coupons to oxygen in alkaline solution [10].

Figure 3, shows the corrosion rate of exposed and unexposed reinforcing steel bar coupons in 1M NaCl solution. The plots of the corrosion rates against exposure time showed the rate of corrosion of the exposed coupons in the solution at the top after thirty days. The trend showed an initial decrease in corrosion rate from 4.65×10^{-3} to 3.49×10^{-3} MPY after ten days, subsequently, the rate increased to $3.95 \text{ x } 10^{-3}$MPY after fifteen days, remained relatively steady up to the twentieth day then decreased again to $3.22 \text{ x } 10^{-3}$MPY after the twenty fifth day and thereafter rose finally to a rate of $3.88 \text{ x } 10^{-3}$ after thirty days. This is an evidence of lack of coherence of initial $Fe(OH)_2$ deposit that tends to obstruct corrosion of the metal surface in the NaCl solution [Talbot and Talbot, 1998]. The unexposed coupons have lower corrosion rates of 3.1×10^{-3} to 3.23×10^{-3} MPY than the exposed ones of 4.65×10^{-3} to 3.88×10^{-3} MPY after thirty days save twenty and twenty five days probably due to the resistance of the surface layer that was more coherent and protective in the salt solution.

Conclusions

The study was embarked upon by the researchers with the knowledge that protective rusty layer formed when low alloy steel is exposed outdoor is corrosion resistant and also that $Fe(OH)_2$ deposit, though obstructs diffusion of oxygen to metal surface lacks the coherence needed to protect iron. Based on these facts, reinforcing steel bar was exposed to rainfall and immersed in 1M HCl, 1M NaOH and 1M NaCl. This was compared with unexposed one in the same media and the following conclusions have been deduced.

At the monitored room temperature range of 25^oC to 32^oC, exposed and unexposed steel bar corroded in 1M HCl, 1M NaOH, 1M NaCl solutions. The rainfall exposed steel bar had a better corrosion resistance than unexposed one in 1M HCl, but poorer in 1M NaCl solutions.

Finally, both exposed and unexposed steel bar corroded in 1M NaOH at the same rate.

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