

Effect of 0.05M NaCl on Corrosion of Coated Reinforcing Steels in Concrete.

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ABSTRACT

An experimental study of the corrosion protection and control of reinforcing steels in concrete is reported. The reinforcing steels were coated with local coating materials (i) bitumen, (ii) enamel paint, and (iii) local anti-rust paint. The reinforced concrete samples were immersed in a 0.05M NaCl solution. The study reveals the protection offered by these coatings in the sodium chloride solution. The study also reveals that the coatings used on the reinforcing steels have good corrosion protection within the period of the experimental study but this cannot be guaranteed at longer periods of time. The results indicated that the enamel paint coating has the best protection against corrosion in NaCl solution, followed by the bitumen coating, and finally local anti-rust paint coating. The potentials and resistances of the coated reinforcing steels at the end of six weeks of the experiment are as follows:

1. -300mV and 38.4kilo-ohm for control sample,
2. -210mV and 29.8kilo-ohm for sample with bitumen coating,
3. -200mV and 28.1kilo-ohm for sample with enamel paint coating, and
4. -250mV and 34.8kilo-ohm for sample with local anti-rust paint coating.

(Keywords: corrosion, concrete, coatings, steel)

INTRODUCTION

Concrete is one of the most widely used construction materials in the world. The realization that modern concrete structures are not as durable as is anticipated has caused increasing concern amongst architects, structural

engineers, and site contractors alike⁽¹⁾. The corrosion of reinforcing steel in concrete structures due to chemical attack of the embedded steel is a major problem to the structural engineer⁽²⁾. This is because the corrosion products mainly the oxides and carbonates of iron (FeCO_3 , Fe_2CO_3 , Fe_3O_4) which cause internal stresses within the concrete cover resulting in cracking and spalling of reinforced concrete structures and the exposure of fresh steel to the corrosive medium⁽²⁾. This effect is due to changes in volume from initial reactants Fe, CO_2 , and O_2 to the final corrosion products.

Of all the metallurgical problems which confront the engineer and scientist, few can be more economically important than the prevention of metallic corrosion. Billions of dollars are required to repair the damage done by corrosion each year⁽²⁾. Ordinarily, steel in concrete is corrosion resistant because of the presence of a passive film of ferric oxide on its surface^(2, 3). The principal soluble product released during the hydration of cement is calcium hydroxide, and as a result the cement tends to be buffered at a value of approximately pH 12.5^(2, 3). The ferric oxide films on the steel are very stable at such alkaline pH values, even in the absence of oxygen. Corrosion of reinforcing steel can result from physical or chemical breakdown of concrete and the access of the external environment to steel, chemical degradation of steel passivity by aggressive ions like chlorides; (Cl^-), sulphates; (SO_4^{2-}) and nitrates (NO_3^{2-}). Under the influence of these factors, the integrity of the reinforced concrete structure is no longer guaranteed⁽²⁾.

Extensive and intensive research works have been done on the subject of corrosion of steel embedded in concrete. Earlier researchers have shown that the simulated environments namely Carbonates, H_2SO_4 , HCL and HNO_3 really induced the corrosion of reinforced concrete

structure and that the concrete cover provides to some extent the protection of the reinforcing steel in the concrete⁽³⁾. The objective of this work is therefore to look into the effect(s) of chloride attack on the protected/coated reinforced steels in the concrete slabs and consequently controlling the rate of corrosion of the reinforced concrete structure. This involves the making of twelve reinforced concrete slabs denoted by alphabetic notations A to L and sodium chloride (0.05M NaCl) used as the simulated environment. The reinforcing steels were coated with bitumen, enamel paint, local anti-rust paint, and a similar specimen with no coating on the reinforcing steel as the reference material.

SAMPLE PREPARATION

The samples made were concrete blocks with protected or coated reinforcing steel fixed at 50mm thickness, 25mm thickness, and 10mm thickness of the slab. The dimensions of the specimens were 160mm long by 100mm thick by 100mm wide (160 x 100 x 100). The elemental weight percent compositions of the reinforcing steel are given in Table 1.

MOULD PREPARATION

The mould was designed to produce the required shape of the specimen (concrete slab). The mould material used was wood since wood is easily shaped, worked, or joined to form complex shapes. They are light in weight, easily available, and economical. The mould box was made such that the interior dimensions are 160mm long x 100mm thick x 100mm wide and the hinges at the corners of the mould aid easy de-moulding.

CONCRETE MIX PREPARATION

The concrete mix was comprised of cement (Portland brand), fine aggregates (sand), coarse aggregates (gravel), and water.

The ratio of the concrete mix is 1:2:4; (i.e. cement: sand: gravel ratio and the water-cement ratio were 0.45).

The measurements of the quantities were done in kilograms;

e.g. Cement = 5kg,
Sand = 10kg
Gravel = 20kg.

The ingredients were thoroughly mixed and water was measured (water = 2.25kg) and added and mixing continued until a uniformly mixed concrete was obtained forming a concrete paste. The mould material was cleaned and painted with mould oil to facilitate de-moulding and the concrete paste was fed into the mould. The mould was tapped when it was half filled and also tapped when it was filled to the brim so that the entire space in the mould was filled in order to avoid the porosity of the concrete block.

SURFACE PREPARATIONS OF THE REINFORCING STEELS

Before the application of coating on the steel rods, the surface of the substrates (i.e. rods) were prepared to get rid of materials like mill scales, grease, rust, oil, and dirt. Emery papers of different grades were used to polish the surface of the steel rods until a cleaned surface was obtained. The steel rods were further cleaned by rubbing with solvent (petrol) to remove any contaminant on its surface.

Table 1: Composition of the Reinforcing Steel (Wt %) as Supplied by the Manufacturer.

Steel Grade	Element (wt %)										
	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	V
Mild Steel	0.115	0.15	0.2	0.01	0.01	0.12	0.06	0.121	0.004	0.152	0.024

COATING TECHNIQUES

1. **Bitumen:** An organic solvent (kerosene) in suitable amounts was used to dissolve the bitumen. The steel rods were coated by hot dipping in bitumen heated in a water bath to about 120°C and allowed to dry in air.

2. **Enamel Paint:** Brushing is by far the commonest method of paint application; the coating was therefore applied by brushing and allowed to dry under sunlight.

3. **Local Anti-Rust Paint:** Like the bitumen, the anti-rust paint was also dissolved in suitable amount of kerosene. The steel rods were coated by the use of brush and allowed to dry under sunlight.

It should be noted that each coating was carried out on three reinforcing steels giving a total of nine coated samples for three different concrete covers. Three steel rods were uncoated and served as the control samples.

METAL INSERTIONS

The steel rods were cut to a dimension of 190mm long and 12mm diameter. After drying, the coated reinforcing steels were inserted into the concrete mix. To each concrete mix, one coated steel rod was inserted to reinforce the sample while still in paste form. The steel rod passed through the opening made at both ends of the mould since the rod is 30mm longer than the length of the mould. The specimen was allowed to gain enough strength before de-moulding, to avoid the collapsing of the concrete mix. The time interval tolerated was 3 – 4 hours.

CURING

Curing is the process of allowing the specimen (concrete blocks) to grow in hardness and in strength and allowing the hydration reaction to proceed to an appreciable extent after de-moulding. The specimens were cured for a period of four weeks in a wet atmosphere (water). This contributes to the durability of the concrete specimen. The sketch of the experimental sample is shown in the figure below where the surfaces of the metal were marked X and Y.

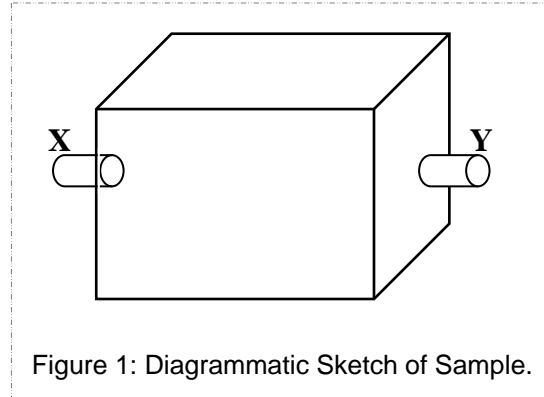


Figure 1: Diagrammatic Sketch of Sample.

ENVIRONMENT

The experimental samples were immersed completely in a sodium chloride environment with a concentration of 0.05M.

Preparation of 0.05M Sodium Chloride Solutions

$$\begin{aligned} \text{Molar mass of NaCl} &= 23 + 35.5 \\ &= 58.5\text{g} \end{aligned}$$

1M solution contain 58.5g of NaCl / liter

Therefore, 0.05M Solution will contain:

$$\begin{aligned} &\frac{58.5\text{g} \times 0.05\text{M} \times 25\text{litres}}{1\text{M}} \\ &= 73.125\text{g / liter} \end{aligned}$$

The sodium chloride was dissolved in 25 litres of distilled water to obtain the required concentration as calculated above. Twelve (12) experimental samples in all were made with the reinforcing rod placed at different thickness of the concrete slab (i.e. 10mm, 25mm, and 50mm). This thickness is referred to as the concrete cover.

The samples were labeled alphabetically, from A to L. The order of labeling and coating on the reinforcing steel rod in the concrete is shown in Table 2. The samples labeled A, B, and C were used as the control experiment, hence, the reinforcing steel rods were not coated.

POTENTIAL AND RESISTANCE MEASUREMENT

A model 8010A digital multimeter was used in the potential survey and resistance probes of the experimental samples. The digital multimeter is a very sensitive electronic instrument used in measuring current (in amperes) ranging from 200 μ A to 2,000A, resistance (in ohms), ranging from 2 ohm to 2,000ohms, and potential (in volts) ranging from 200mV to 2,000V. This instrument was appropriate for this experiment because it can measure a very small potential. Thus each concrete test block which was immersed in the

simulated environment was removed after a period of seven (7) days and its potential and resistance were measured using the digital multimeter.

RESULTS

The potentials and resistance were obtained with the help of a 8010A digital multimeter at intervals of seven (7) days. The results obtained are tabulated on Tables 3 and 4 and displayed in Figures 2 – 11.

Table 2: Order of Labeling and Coating of Reinforcing Steels in Concrete.

Coating	Concrete Cover(mm)		
	10	25	50
Control Sample	A	B	C
Bitumen	D	E	F
Enamel	G	H	I
Antirust	J	K	L

Table 3: Potential (mV) of Reinforcing Steels in Concrete Immersed in Sodium Chloride Solution.

Coating/Concrete Cover	Sample Labeling	Time(days)						
		0	7	14	21	28	35	42
Control Sample								
10mm Thickness	A	-130	-290	-260	-390	-400	-330	-410
25mm Thickness	B	-210	-270	-190	-210	-280	-250	-310
50mm Thickness	C	-170	-220	-250	-270	-240	-290	-300
Bitumen								
10mm Thickness	D	-60	-140	-190	-270	-290	-250	-280
25mm Thickness	E	-50	-90	-160	-200	-220	-180	-250
50mm Thickness	F	-40	-60	-120	-190	-210	-160	-210
Enamel Paint								
10mm Thickness	G	-40	-120	-220	-250	-280	-230	-270
25mm Thickness	H	-30	-70	-180	-220	-230	-190	-240
50mm Thickness	I	-20	-50	-110	-160	-190	-150	-200
Local Antirust Paint								
10mm Thickness	J	-90	-130	-170	-240	-300	-240	-290
25mm Thickness	K	-80	-100	-140	-180	-210	-260	-260
50mm Thickness	L	-60	-80	-130	-170	-200	-250	-250

Table 4: Resistance (K-ohm) of Reinforcing Steels in Concrete Immersed in Sodium Chloride Solution.

Coating/Concrete Cover	Sample Labeling	Time(days)						
		0	7	14	21	28	35	42
Control Sample								
10mm Thickness	A	16.2	34.4	30.1	45.7	46.5	42.2	46.9
25mm Thickness	B	16.8	31.7	29.8	42.4	43.5	38.5	39.6
50mm Thickness	C	16.7	29.4	31.5	35.5	34.5	36.8	38.4
Bitumen								
10mm Thickness	D	19.9	25.7	31.5	36.5	38.7	20.7	33.5
25mm Thickness	E	18.7	24	31	35.7	38.3	20.3	37.1
50mm Thickness	F	19.8	23.7	36.9	38.4	39.4	25.4	29.8
Enamel Paint								
10mm Thickness	G	18.3	26.2	30.5	33.5	34.5	24.5	37.3
25mm Thickness	H	18.1	23.7	29.7	31.5	33.5	23.5	35.8
50mm Thickness	I	19.7	22.3	28.6	33.5	38.7	20.7	28.1
Local Antirust Paint								
10mm Thickness	J	18.8	26.5	33.4	34.4	35.3	21.3	31.8
25mm Thickness	K	18.8	24.8	29.1	30.5	32.8	24.8	30.9
50mm Thickness	L	18.2	24.6	27.7	30.6	31.7	21.7	34.8

Figure 2 represents the plot of potential Vs time curve of the coated reinforcing steels in concrete with a cover of 10mm. It also included the potential Vs time curve of uncoated reinforcing steel in concrete used as the control experiment. Thus in all, there are four curves on this plot and the corresponding alphabetical labeling are A, B, G and J as shown on Table 4.

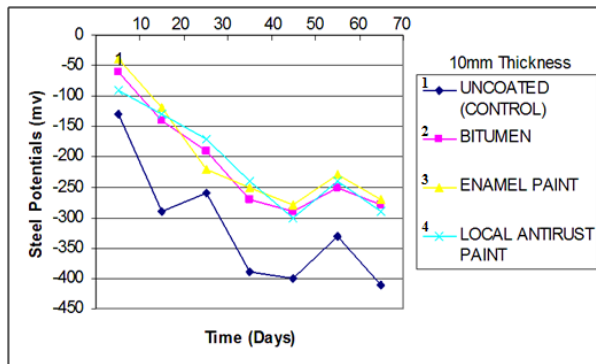


Figure 2: Graph of Potential vs. Time of Reinforcing Steels in Concrete Immersed in Sodium Chloride Solution.

Figures 3 and 4 also show the plots of potential vs. time curves of the coated reinforcing steels in concrete with concrete covers of 25mm and 50mm, respectively. The plots also included the potential vs. time curves of their respective uncoated reinforcing steels in concrete used as their control experiments. The corresponding alphabetical labeling are B, E, H, and K for 25mm thickness and C, F, I and L for 50mm thickness.

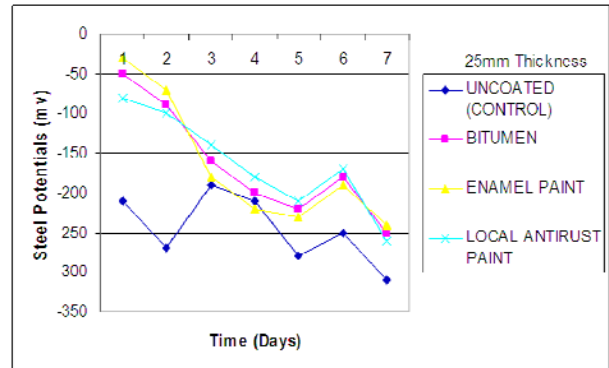


Figure 3: Graph of Potential vs. Time of Reinforcing Steels in Concrete Immersed in Sodium Chloride Solution.

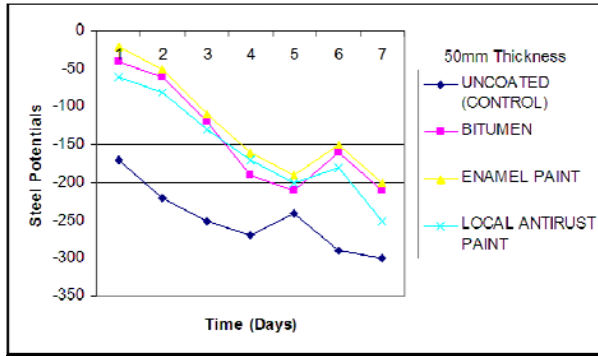


Figure 4: Graph of Potential vs. Time of Reinforcing Steels in Concrete Immersed in Sodium Chloride Solution.

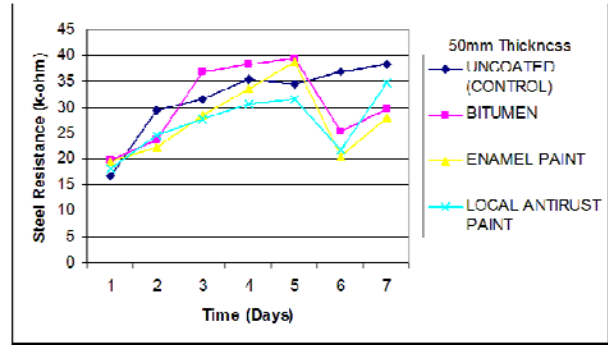


Figure 7: Graph of Resistance vs. Time of Reinforcing Steels in Concrete Immersed in Sodium Chloride Solution.

Figures 5, 6 and 7 show the plots of resistance vs. time curve of the coated reinforcing steels in concrete with their respective concrete covers. The plots also included the resistance vs. time curve of uncoated reinforcing steel in concrete used as their control experiment. Thus in all, there are four curves on each plot.

Figures 8, 9, 10, and 11 show the results obtained for the effect of concrete covers on the corrosion of reinforcing steels in concrete.

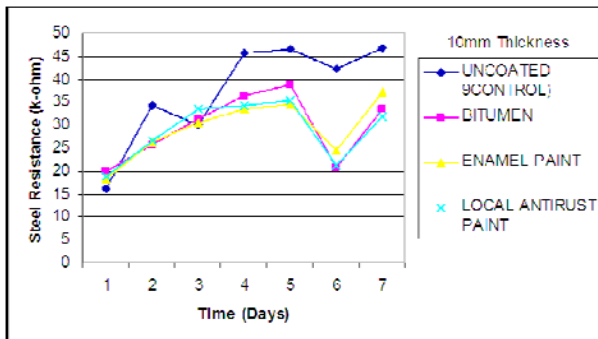


Figure 5: Graph of Resistance vs. Time of Reinforcing Steels in Concrete Immersed in Sodium Chloride Solution.

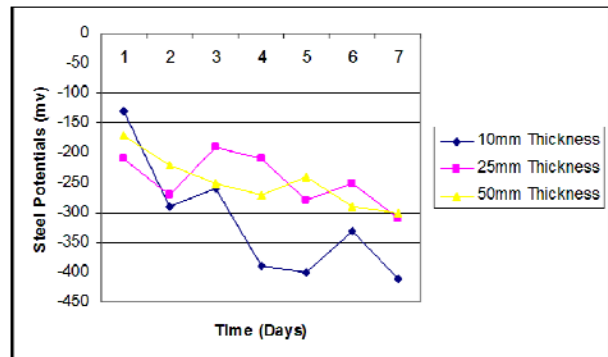


Figure 8: Effect of Concrete Covers on the Corrosion Rate of Reinforcing Steels (uncoated) Immersed in Sodium Chloride Solution.

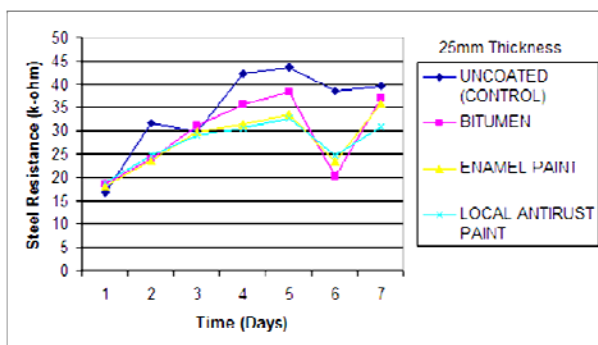


Figure 6: Graph of Resistance vs. Time of Reinforcing Steels in Concrete Immersed in Sodium Chloride Solution.

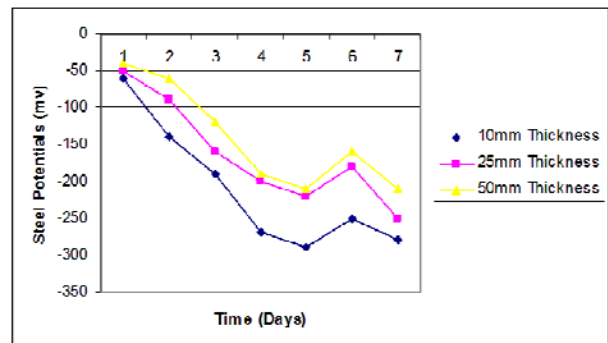


Figure 9: Effect of Concrete Covers on the Corrosion Rate of Reinforcing Steels (Bitumen coating) Immersed in Sodium Chloride Solution.

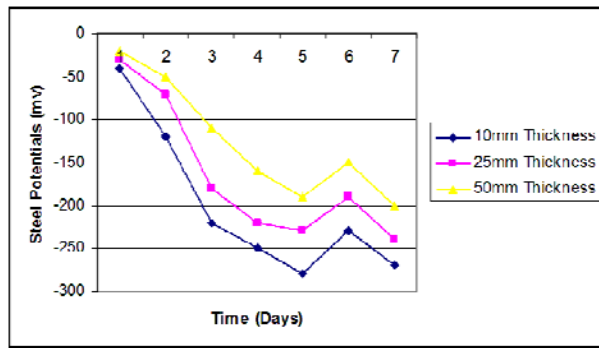


Figure 10: Effect of Concrete Covers on the Corrosion Rate of Reinforcing Steels (Enamel paint coating) Immersed in Sodium Chloride Solution.

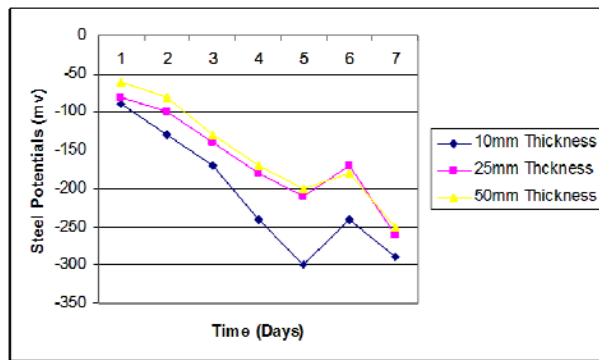


Figure 11: Effect of Concrete Covers on the Corrosion Rate of Reinforcing Steels (Enamel paint coating) Immersed in Sodium Chloride Solution.

DISCUSSION

The curve marked 1 on Figure 2 represents the potential vs. time plot of the control experiment for 10mm concrete cover.

During the first week of experimental study, there was a drop in potential from -130V to -290mV which shows that active corrosion process has taken place. This shows that during the first week, the chloride ions have gained access to the concrete–steel interface causing intense localized attack.

During the second week, the potential rise from -290mV to -260mV which could be as a result of passivity. Although the precise nature of this passive film is unknown it isolates the steel from

the environment and slows further corrosion as long as the film is intact.

Within the third week, the potential had dropped from -260mV to -390mV which shows that depassivation must have taken place as a result intense localized attack by chloride ions.

Within the fifth week, the potential increased from -400mV to -330mV as a result of passivity.

During the sixth week, there was a drop in potential from -330mV to -410mV. This could be as a result of depassivation of the oxide film and consequently the outset of corrosion.

The curve marked 2 on Figure 2 represents the potential vs. time plot of the reinforcing steel coated with bitumen for 10mm concrete cover.

During the first week of the experimental study there was a drop in potential from -60mV to -140mV which shows that active corrosion process has taken place. As it is seen from the graph, the corrosion process was not severe when compared with the corrosion process of the control experiment. This shows a difference in potential of -15mV between the bitumen coated reinforcing steel and the control experiment. This shows that the bitumen coating offered protection to the reinforcing steel.

From the second week to the fourth week, there was a continuous drop in the potential which shows that active corrosion process continued but not as severe when compared with the control experiment. The corrosion process on the bitumen coated reinforcing steel was due to exposure of certain areas on the steel surface to higher concentration of chlorides which act as anodic areas (Berke et al., 1988). The large cathodic area-anodic area ratios generated on the steel surface rapidly increase the corrosion rate as shown in Figure 12.

The large cathodic areas and anodic areas were as a result of the fact that chloride ions within the concrete are usually not distributed uniformly (Hansson et al 2007). This corrosion process can also be attributed to the damage done on bitumen coating by the alkaline reaction of the adjacent concrete which gave the chloride ions access to the reinforcing steel surface.

During the fifth week, the potential increased from -290mV to -250mV; this could be as a result of passivity. Within the sixth week, the potential dropped from -250mV to -280mV which could be as a result of depassivation as more anodic areas formed.

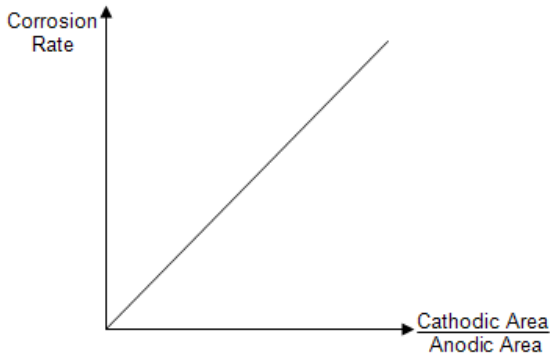


Figure 12: Effect of Cathodic Area/Anodic Area Ratio on Rate of Corrosion of Reinforcing Steel Immersed in Sodium Chloride Solution.

The curve marked 3 on Figure 2 represents the potential vs. time plot of the reinforcing steel coated with enamel paint for 10mm concrete cover.

During the first week of the experiment, there was a drop in potential from the -40mV to -120mV which shows that active corrosion process has taken place. From the graph, it is seen that the corrosion process was not severe when compared with corrosion process of the control experiment. There was a difference in potential of -190mV between the enamel paint coated reinforcing steel and the control sample. This shows that the enamel paint coating offered better protection to the reinforcing steel when compared with the bitumen coating.

From the second week to the fourth week of the experiment, there was a continuous drop in potential which shows that active corrosion process continued but was not as severe when compared with the control experiment. The protection of enamel paint has a similar behavior to that of bitumen coating but enamel paint was better until the end of the experiment except within the second week.

During the fifth week, the potential increased from -280mV to -230mV; this could be as a result of passivity.

Within the sixth week, the potential dropped from -230mV to -270mV; this could be as a result of depassivation and more anodic areas being formed.

The curve marked 4 on Figure 2 represents the potential vs. time curve of the reinforcing steel coated with local anti-rust paint. From the graph it is seen that the local anti-rust coating has a similar protection behavior to that of bitumen and enamel paint coatings. But the protection decreased with the time when compared with bitumen and enamel paint coatings.

During the first week, the protection offered by the local anti-rust was better than that of the bitumen and enamel paint coatings. This can be attributed to less anodic areas formed on the surface of the anti-rust coated reinforcing steel. Within the fourth week and sixth week, the protection has decreased when compared with other coatings which could also be as a result of more anodic areas being formed.

In Figures 3 and 4, there were similar behaviors of the effect of chloride on the coated reinforcing steel samples when the potential vs. time curves are compared with the curves on Figure 2.

On Figure 4, the curve marked 1 represents the potential vs. time curve of the control experiment for 50mm concrete cover. During the first week of experimental study, there was a drop in potential from -170mV to -220mV which shows that active corrosion process has taken place.

The corrosion process was reduced when compared with the curve marked 1 on Figure 2. This is due to the concrete cover to the reinforcing steel which has reduced the ingress of the chloride ions. From the second week to the third week, there was continuous drop in potential which shows that active corrosion process continued. During the fourth week, the potential increased from -270mV to -240mV; this could be as a result of passivity.

From the fifth week to the sixth week, the potential drop from -240mV to -300mV which maybe as a result of depassivation of the oxide films, formation of iron chloride due to intense

localized attack, and large cathodic area-anodic area ratios.

The curves on Figure 4 shows the potential vs. time curves of the reinforcing steels coated with bitumen, enamel paint and local anti-rust paint respectively. From the graph, it is clearly seen that the coatings offered good protection to the reinforcing steels with enamel paint having the best protection. This could be as a result of fewer amounts of anodic areas formed on the reinforcing steel surface.

The curves on Figures 8, 9, 10, and 11 show potential vs. time plots of reinforced steels immersed in sodium chloride solution with respect to concrete covers. The plots show the effect of varying the position of the reinforcing steels in concrete.

The curves on Figure 8 show the effect of 10mm, 25mm, and 50mm concrete cover on the corrosion rate of the control sample. From the graph, it can be seen that the 10mm thickness has the least protection throughout the period of investigations. It should be noted that the permeability of the concrete cover determines the relative ease with which the concrete cover can become saturated with the simulated environment. This explains why the 10mm thickness has the least protection because it has been saturated with the sodium chloride solution. This is also the same case for 25mm and 50mm concrete covers, but with different severity, as shown in Figure 8.

The curves in Figure 9 shows the effect of concrete cover on the corrosion rate of bitumen coated reinforcing steels. From the graph, it is seen that the concrete cover offered good protection along with bitumen coating on the reinforcing steel. The graph also indicated that 50mm thickness offered the best protection, followed by 25mm, and lastly 10mm thickness. Similarly, the result obtained for enamel paint coated reinforcing steels on Figure 10 corresponds to that bitumen coating. From the graphs, it can be seen that the concrete cover offered good corrosion protection alongside with enamel paint coating on reinforcing steel when compared to results obtained for the control experiment.

Lastly, the curves on Figure 11 showed the results obtained for local anti-rust paint coated reinforcing steels at different concrete covers.

The results obtained are also similar to that of bitumen and enamel paint coatings, respectively. But during the fifth week, the protection offered by the 50mm thickness dropped below that of 25mm thickness. This could be as a result of more anodic areas on the reinforcing steels.

CONCLUSION

From the experimental results, the following conclusions can be drawn:

1. That the coating (i.e. bitumen, enamel paint, and local anti-rust paint) offered good protection against corrosion within the period of experimental investigations. However, this protection could not be guaranteed at longer period.
2. That the enamel paint coating has the best protection against corrosion, followed by bitumen coating, and lastly local anti-rust paint coating in the corrosive media used (i.e. sodium chloride solution).
3. That the concrete cover to reinforcing steels also offered good corrosion protection with the 50mm thickness having the best protection, followed by 25mm thickness, and finally 10mm thickness.
4. That the simulated environment (0.05M NaCl) really induced the corrosion of the coated reinforcing steels when compared to the corrosion of the uncoated reinforcing steel in concrete.

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