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Efficiencies of Different Techniques to Protect Rebars Against Corrosion

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Abstract: Corrosion of steel reinforcement is considered one of the major causes of reinforced concrete deterioration. In the last few decades, researchers studied many different rebar protection techniques against corrosion. Three famous techniques were considered in this research, which are rebars protective coats, sacrificial anode and impressed current. Rebars protective coats are the most used technique in small projects. They are produced with different trade names according to the manufacture. On other hand, sacrificial Anode technique is recommended for aggressive environments. Finally, impressed current technique is usually used for large and corrosion sensitive structures. The aim of this research is to compare the protection efficiency of each of these three techniques. In order to achieve that goal, two experimental programs were carried out; the first program measured the protection efficiency in terms of rebars mass loss using sixteen lollypop samples. The program tested the efficiency of two types of protective coats, three types of sacrificial anodes besides the impressed current using two concrete grades. The second program measured the protection efficiency in terms of loss in structural capacity using six (100x100x1500mm) concrete simple beams. Only one type of protective coating is used besides the impressed current technique. In both programs, all samples were tested using accelerated corrosion test and results were compared to the control samples. Programs results showed that impressed current is the most effective protection technique because it prevents the corrosion completely. On other hand, the efficiency of sacrificed anode technique depends on the activity of the anode material and finally, the efficiency of protected coats dependents on material base of the coat.

Keywords: Protection against corrosion; Protective coats; Sacrificed anode; Impressed current.

I. INTRODUCTION

Life time issues related to concrete structures are some of the most important subjects in civil engineering today. Reinforcement steel corrosion is one of the most significant life time issues; it causes rust, cracks, cover splitting, and structural degradation, it is also considered one of the main causes of damaging of bridges and infrastructure [3]. Many articles had been studied in details different causes of corrosion, corrosion mechanism, corrosion assessment and different protection methods. Most of corrosion studies done in the last few decades concentrated more on the different methods of protection.

Protective coatings (usually Zinc based) are one of the most famous rebars protection techniques for both new and repaired concrete structures [3]. On other hand cathodic protection is considered the most effective method to stop steel corrosion in existing structures or to prevent it in the new structures. There are two main types of cathodic protection: Sacrificed Anode Cathodic Protection system (SACP) and Impressed Current Cathodic Protection system (ICCP). (SACP) technique depends of burying bars of metal more active than steel in concrete elements; this metal will be corroded and dissolved instead of steel rebars. The main concept of (ICCP) depends on passing electrical current in the rebars with intensity higher than the corrosion current and in opposite direction to cancel it [1, 4, 6 & 8].

Bahekar et al. (2017), studied the rebar protection using (ICCP) for beams strengthened with CRFP. 8. Zhang et al. (2018) studied the degradation of the anode–concrete interface in cathodic protection. Oleiwi et al. (2018) carried out an experimental program to investigate the efficiency cathodic protection for concrete elements contaminated with chloride. Finally, Goyal et al. (2019) studied the potential shift effect on rebars corrosion rate.

II. OBJECTIVES

The main aim of this research is to investigate the efficiency of three famous rebars protection techniques against corrosion. These techniques are protective coats, sacrificial anode and impressed current. The protection efficiency of was measured in terms of mass loss and structural capacity loss. Two experimental programs were carried out; the first program measured the protection efficiency in terms of rebars mass loss using sixteen lollypop samples. The program tested the efficiency of two types of protective coats, three types of sacrificial anodes besides the impressed current using two concrete grades. The second program measured the protection efficiency in terms of loss in structural capacity using six (100x100x1500mm) concrete simple beams. Only one type of protective coating is used besides the impressed current technique. In both programs, all samples were tested using accelerated corrosion test and results were compared to the control samples.

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III. MATERIALS & TEST SAMPLES

A. Concrete Mix

The target cube strength of the concrete mix was 250 Kg/cm^2 after 28 days, the properties of the used materials are:

- Cement: Ordinary Portland Cement grade R 42.5
- Course aggregate: crushed stone
- Fine aggregate: natural sand, fineness modulus of 2.30
- Long. reinforcement: 12 mm diameter deformed ribs of grade 40/60
- Stirrups: 8 mm diameter plain ribs of grade 24/35

Table-I shows the sieve analysis results for both coarse and fine aggregates, while Table-II shows the physical properties of them. Table-III shows the required quantities for (1 m^3) of concrete. The average value of compressive strength of the tested cubes after 28 days was 266 Kg/cm^2

All the samples were cured by wet burlap until testing.

Table- I: Sieve analysis results for both coarse and fine aggregates

Fine Aggregate	**Sieve size (mm)**	4.75	2.36	1.18	0.60	0.30	0.15
	Pass %	98	95	85.5	45.5	13	2.5
Coarse Aggregate	**Sieve size (mm)**	37.5	31.5	28.0	20.0	10.0	5.0
	Pass %	100	100	100	100	57.8	2.5

Table- II: physical Properties of both coarse and fine aggregates

Property	Fine Agg.	Coarse Agg.
Specific gravity	2.18	2.667
Unit weight (t/m^3)	1.535	1.527
fine materials (by volume) %	1.8	0.5
Absorption %	…..	1.7

Table- III: Required quantities for (1 m^3) of concrete

Cement (OPC) (Kg)	Sand (Kg)	Crushed Stone (Kg)	Water (Liter)
350	725	880	210

B. Test Samples

The 1st experimental program consists of sixteen lollypop concrete samples were prepared using the mix proportions given in Table-III. All samples had cylindrical shape with diameter of 100mm and height of 200mm. Each sample had a central rebar of 12mm in diameter as shown in Fig. 1. These rebars were protected and tested as shown in Table IV.

The 2nd experimental program consists of six concrete beams (100x100x1500mm). Each beam had longitudinally reinforcement ratio of 1.0 % (4 bars of diameter 12mm, grade 40/60). Eight mild steel stirrups of 8 mm diameter were used with spacing 200mm along the beam as shown in Fig. 2. Reinforcement rebars were protected and tested as shown in Table IV.

Galvano-static method were used subject all test samples (beams & lollypops) accelerated corrosion. In this method, an electrical current is injected through the reinforcing bar using fixed potential across the bar (anode) and the pipe around the sample (cathode) [2], [5] &[7].

The intensity of the current passes through the circuit was calculated (in Ampere) by dividing the reading of the connected voltmeter between the connectors of the fixed resistor (in volts) by the resistor value (in Ohms). The chosen value for the fixed resistor was 100 Ohms.

Test samples were submerged in a 15% Sodium chloride (NaCl) solution at temperature varied between 20°C to 30°C. The applied constant potential difference on the circuit was 15 voltages. The cathode (steel pipe) was immersed in the solution and was cleaned each two hours to remove any salt deposits from its surface.

The corrosion cell is shown in Fig. 3.

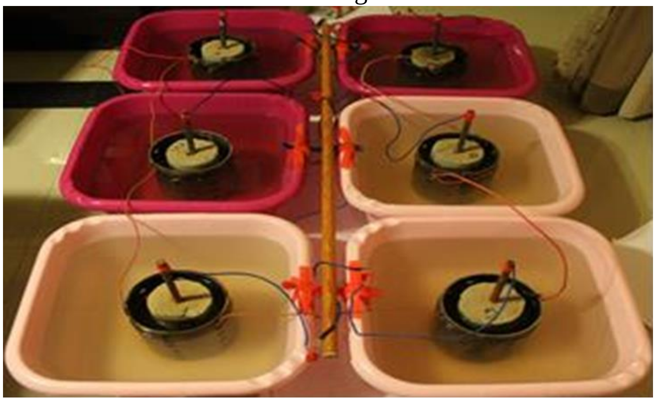


Fig. 1.The lollypop samples during the test

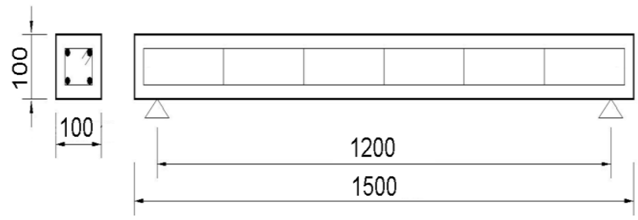


Fig. 2.Typical dimensions of RC beams

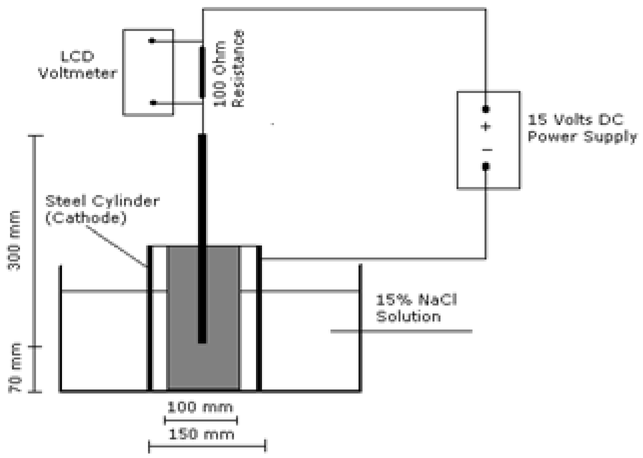


Fig. 3.Accelerated Corrosion Cell

Table- IV: Samples' Details

Sample		Protection technique	Exposure	Test
16 Lollypop Samples	A1, A2	Control Samples	Accelerated Corrosion	Total Mass Loss Test
	B1, B2	Coated by Kemapoxy-131		
	B3, B4	Coated by Sika Zinc-rich-2		
	C1, C2	Sacrificed anode by AL		
	C3, C4	Sacrificed anode by Zn		
	C5, C6	Sacrificed anode by Mg		
	D1, D2	Impressed Current, Fcu=250 kg/cm^2		
	D1, D2	Impressed Current, Fcu=150 kg/cm^2		
6 RC Beams	2 beams	Control Samples	Accelerated Corrosion	Three Point Load Flexure Test
	2 beams	Coated by Kemapoxy-131		
	2 beams	Impressed Current, Fcu=250 kg/cm^2		

IV. TEST PROCEDURE AND RESULTS

The Lollypop samples were used to figure out the total mass loss for each protection technique. During the accelerated corrosion test process, the current intensity values "I" was calculated and recorded each 2 hours of the test duration (250 hours). As mentioned above, the corrosion current intensity (I) is calculated by dividing the potential difference across the fixed resistance (V) by the fixed resistance value (100Ω) as shown in Eq.(1).

$$I\ (Ampere) = V\ (Volt) / R\ (Ohm) \qquad (1)$$

The total mass loss is calculated as the area below the curve of corrosion current vs. time using Faraday's equation:

$$\text{Total mass loss (gm)} = [M / (Z*F)]\ [\int I.dt] \qquad (2)$$

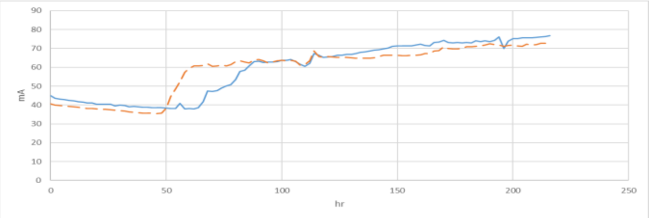
Where: M = 55.85 gm/mol (Atomic weight of iron)
∫I .dt = Total electrical charge.
Z = 2.0 (Ionic charge for iron).
F = 96485.3 C/mole (Faraday's constant)

Table-V shows the total mass loss percentage (Mt %) for all lollypop samples.

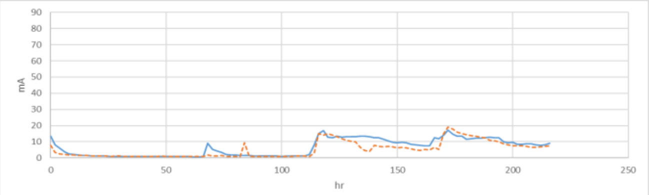
Table-V: Total mass loss percentage for lollypop samples

Protection Technique	Sample	Avg. (Mt %)	Avg. Mt (%)
Control Samples	A1, A2	4.71, 4.56	4.64
Coated by Kemapoxy-131	B1, B2	0.68, 0.74	0.71
Coated by Sika Zinc-rich-2	B3, B4	1.10, 0.63	0.87
Sacrificed anode by AL	C1, C2	0.16, 0.35	0.26
Sacrificed anode by Zn	C3, C4	0.46, 0.71	0.59
sacrificed anode by Mg	C5, C6	2.17, 2.18	2.18
Impressed Current, Fcu=250 kg/cm^2	D1, D2	---	0.00
Impressed Current, Fcu=150 kg/cm^2	D1, D2	---	0.00

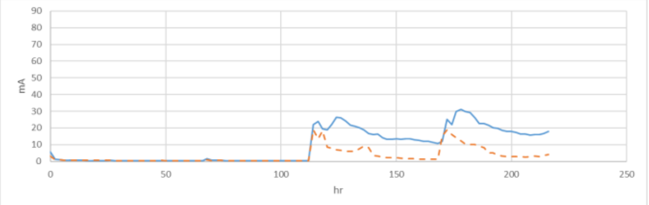
Fig. 4 shows the "Time - Current" relationship for lollypop samples for each protection technique. Fig. 5 gives the total mass loss % for all lollypops as a percentage from the control sample.



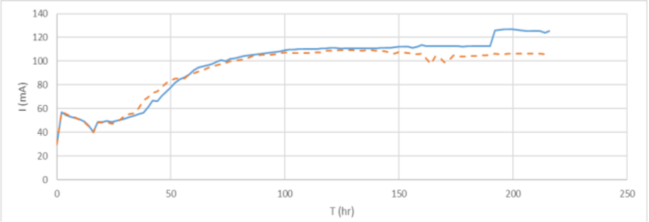
a) Control samples (A1, A2)



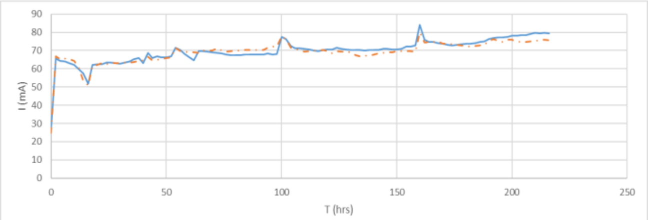
b) Coated by Kemapoxy-131 (B1, B2)



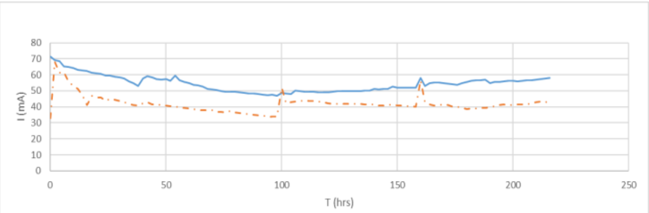
c) Coated by Sika Zinc-rich-2 (B3, B4)



d) Sacrificed anode using AL (C1, C2)



e) Sacrificed anode using Zn (C3, C4)



f) Sacrificed anode using Mg (C5, C6)

Fig. 4.(Time – Current) relationship for lollypop samples for each protection technique

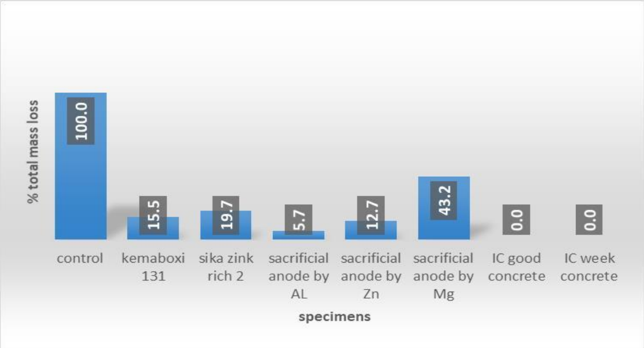


Fig. 5.Total mass loss % for all lollypops as a ratio from the control Samples

The six beams of the 2nd experimental program were loaded with concentered loaded at mid span using steel frame connecting each two beams together as shown in Fig. 6. The steel frames were tightened to cause deflection of 2.0mm for each beam (total 4.0 mm). This deflection is equivalent to 1.0 tons load at mid span of each beam which generates stresses near to normal working condition. The stresses beams were tested using the accelerated corrosion cell for 250 hours but without recording corrosion current with time. The aim of using those beams is to figure out how the protection technique can affect the failure loads of the beams.

After accelerated corrosion, the six beams were tested using three points flexural test. Samples span was 1200 mm and they were gradually loaded in the middle until failure. The recorded failure loads for the six samples are shown in Table-VI; Fig. 7 shows the failure loads as a percentage of control samples.

Fig. 6. Loading beams using steel frame connecting each two beams together

Table-VI: Failure loads (after corrosion) for RC beams

Protection Technique	Failure Load (kg)	Avg. Failure Load (kg)
Control Samples	1000, 1500	1250
Coated by Kemapoxy-131	1850, 1900	1875
Impressed Current, Fcu=250 kg/cm^2	2000, 2050	2025

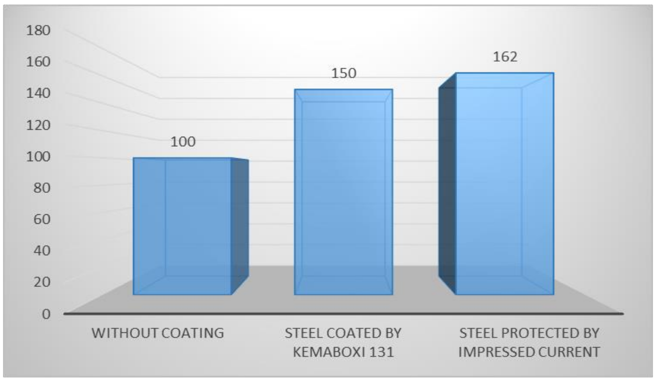


Fig. 7.Failure loads of beams as a % from Control beams

V. DISCUSSION AND CONCLUSIONS

The results of the 1st experimental program illustrate some important points as follows:

- Fig. 4 shows that the corrosion process started after 110 hours (nearly half the test duration) in case of using protective coats. This delay had major effect on the total mass loss. It also indicates that Kemapoxy-131 is slightly better than Sika Zinc-rich-2

Figure 4 also shows that the average current values in the case of sacrificed anodes are more than in the case of the control sample, indicating that the erosion in the sacrificed anode is faster than in steel. It also shows that the more active the sacrificed metal, the greater the value of the current passing through the circuit and the faster the corrosion and dissolution of the anode. Accordingly, the best sacrificed metals are Aluminum, Zinc and Magnesium in order.

- Although Magnesium anode should provide better protection than Aluminum and Zinc because it is more active than them, but it actually showed the worst protection level. This is because the required weight of the (Mg) anode was underestimated; hence, it was completely corroded before the end of the test leaving the concrete sample unprotected.
- No (Time-Current) curves were plotted for impressed current technique in Fig. 4 because the injected protecting current is higher than the corrosion current and in opposite direction which keeps the value of the corrosion current at zero or less.

- Fig. 5 shows that regardless the concrete strength, the impressed current technique prevents the corrosion completely. On other hand, the protection efficiency of sacrificed anode depends on the activity of the anode metal, the more active the sacrificed metal, the more efficient protection, but for shorter period. Finally, the used protective coats are Zinc based coats, hence, their efficiency are almost the same as Zinc sacrificed anode.

The results of the 2nd experimental program illustrate some important points as follows:

- The theoretical failure load of un-corroded beam is 2000 kg; hence, Table-VI shows that the structural capacity of control beams were reduced to about 63% of its original value. While the capacity of the beams with rebars coated by Kemapoxy-131 were reduced to about 93% of the original value. Finally, the beams protected by impressed current kept 100% of its structural capacity.
- Although, the total mass loss percentage relative to that of control case were 16% & 0.0% for Kemapoxy-131 and impressed current respectively, but the reduction in structural capacity were 7% & 0.0% respectively.

Based on the previous discussion, the results of this research could be concluded in the following points:

- Impressed current is the most efficient protection technique against corrosion because it prevents the corrosion completely.
- The efficiency of the sacrificed anode technique depends on the activity of the anode material. The more active anode material the more efficient protection but for shorter time.
- The efficiency of the protective coats technique depends on the metal base of the coat, since most coats are Zinc based, hence their efficiencies are almost the same as sacrificed Zinc anode.
- Although protection efficiencies measured in terms of total mass loss are different from those measured in terms of structural capacity reduction, but both of then share the same protecting techniques ranking.
- (Cost – Efficiency) combination for each protection technique should be considered in farther studies.

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