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Original Research Article

A Study on Protection of Reinforcing Steel-From Corrosion Using Zinc

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Abstract

Over time, many buildings and structures are exposed to defects such as corrosion of reinforcing steel in different parts of the concrete structure, so it is necessary to repair them directly in order to maintain the sustainability of these structures. The corrosion of steel reinforcement is one of the main causes of premature deterioration, which reduces service life in reinforced concrete structures. This increases the maintenance and repair costs of reinforced concrete structures. In reinforced concrete structures corrosion of steel in a normal state is a very slow process. Accelerated corrosion techniques are generally used in the laboratory to simulate natural corrosion. The aim of this research is to study the protection of reinforcing steel in the concrete from corrosion using accelerated corrosion methods. The objective of this study is to analyze the protection of steel reinforcement in concrete from corrosion using zinc and its effects on steel samples. In this study two types of reinforcing steel (mild & tor steel) are used and each type of steel is coated with protective paint. Mix design was done using ACI method for C30 grade of concrete and four slab samples (300mm × 300mm × 40mm) were cast with steel rebar. In this research a constant current of 0.8 ampere was applied on the steel bar and the reduction in weight of steel bar before and after corrosion was observed. The results show that samples with coating undergoes less corrosion compared to samples without coating in both mild steel and tor steel specimen.

Keywords: Accelerated corrosion, Reinforcing steel, Protective coating, Mild steel, Tor steel.

INTRODUCTION

Corrosion of reinforcing bar provokes premature deterioration of reinforced concrete (RC) structures. It results in loss of cross sectional area of the reinforcing bar and development of cracks in the surrounding concrete. It leads to the reduction of flexural strength, ductility and load carrying capacity of RC elements. In general corrosion was observed in the marine structures and chemical industries. Many reports indicate that it occurred at the crossings, tunnels, and bridges that are exposed to chlorine solutions. The research conducted in this field has helped to provide a better understanding on the nature of corrosion and the factors affecting it. The concrete surrounding the reinforcing steel is usually provided with the necessary protection against corrosion since the modern concrete environment provides the required atmosphere to maintain the stability of the iron oxide layer covering the iron surface.

Iron is found naturally in the form of services or oxides or other interactive products and when extracted from them, it will be unstable due to its tendency to renew the environmental element surrounding it and return again in the form of services and oxides that this process of return is called oxidation or corrosion. The first evidence of corrosion is the brown color of the concrete around the reinforcing steel, and that the color is the result of rust reinforcing steel but often accompanied by cracking or cracks occur after a short period and several tests have been conducted on the reinforced concrete which includes the use of anti-oxidant or protective coating of iron against oxidation has been achieved a lot of success in these areas as the phenomenon of corrosion has decreased significantly.

Causes of Corrosion

Concrete is a base material and the base is the opposite of the acid, and as a rule, the metals are eroded in the acidic atmosphere while the basic environment provides effective protection and that the concrete subject to this rule. It contains microscopic pores which contain solutions with a high concentration of calcium oxides, sodium and potassium, and these oxides are responsible for the concrete base which reaches the limits of ph 12 to13.

The corrosion behavior of any source depends on the concentrations of these components found in the water of the pores and also depends on the movement of ions and gases during these pores. The basement environment leads to the formation of an inactive chemical layer that is not effective on the surface of the reinforcing steel. This layer is characterized by dense and non--permeable. If it covers an entire surface, it prevents further corrosion. This layer is part of the reinforcing steel and the cement material surrounding it. Between them That the existence of a base environment surrounding the reinforcing iron contributes to ensure the survival and stability of the protective layer on the surface of the iron, but may happen to decrease the stability of this class, leading to corrosion, which is often either because of the so--called (carbonization) or because of the attack chlorine ion.

Cathodic protection (CP)

Cathodic Protection (CP) is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell. A simple method of protection connects the metal to be protected to a more easily corroded "sacrificial metal" to act as the anode. The sacrificial metal then corrodes instead of the protected metal. For structures such as long pipelines, where passive galvanic cathodic protection is not adequate, an external DC electrical power source is used to provide sufficient current. Another common application is in galvanized steel, in which a sacrificial coating of zinc on steel parts protects them from rust. Cathodic protection can prevent stress corrosion cracking.

The reactions of half of the chemical cells that occur in the cathodic and anodic regions are the following:

Cathode: 2e-- + H_2O + (1/2) O_2→2(OH)--

Anode: Fe → Fe_2+ + 2e--

The compound Fe $(OH)^2$ is reacted with available oxygen and extra hydroxide, where the red rust is formed insoluble in water. The impressed current technique, consists of applying a constant current from a DC source to the steel embedded in concrete to induce significant corrosion in a short period of time [1].

This study is about protecting rebar from corrosion using zinc. The reasons for choosing this subject is reinforcing steel, which is considered to be one of the most important component elements of a building and whose quality should be high over the years. In addition, reinforcing steel is used in all buildings such as houses, bridges, and dams. It is my idea to add a zinc element in the protection of reinforcing steel from rust provides the building continuity for several years and the prevention of future dangers.

It helps to sustain the building in terms of longevity, maintain the structure of the building in the atmospheric changes, and also reduce the expected material cost of future maintenance, in addition to protection against future hazards that may affect humans.

Cathodic and Anodic Reactions

The reactions of half of the chemical cells that occur in the cathodic and anodic regions are the following:

Cathode: 2e-- + H2O + (1/2) O2→2(OH)--

Anode: Fe → Fe2+ + 2e-

Hydroxyl ions reach OH-- in the anodic region and equivalent to iron ions Fe2+ electrolytic dissolved in water and also from an iron hydroxide solution in anode:

Fe2+ + 2(OH)-- → Fe(OH)2.

The compound Fe (OH)2 is reacted with available oxygen and extra hydroxide, where the red rust is formed insoluble in water.

Accelerated corrosion technique

The impressed current technique, consists of applying a constant current from a DC source to the steel embedded in concrete to induce significant corrosion in a short period of time. This study is about protecting rebar from corrosion using zinc. The reasons for choosing this subject is reinforcing steel, which is considered to be one of the most important component elements of a building and whose quality should be high over the years. In addition, reinforcing steel is used in all buildings such as houses, bridges, and dams. It helps to sustain the building in terms of longevity, maintain the structure of the building in the atmospheric changes, and also reduce the expected material cost of future maintenance, in addition to protection against future hazards that may affect humans.

AIM & OBJECTIVES

- To protect reinforcing steel in concrete from corrosion.
- To analysis method of protecting steel reinforcement in concrete from corrosion.
- To find out the effect of zinc on reinforcing steel

Literature Review

In this study found a grade of two different local industries has been studied in fresh water and seawater, which were compared with weldable low strength (yield strength 300MPa) bars of the same companies. Experimental results revealed that addition of small amount of alloying elements such as Cr, Ni, and Cu improves the corrosion resistance of the steel bars in all test mediums; however, strength levels have no influence the corrosion rate. A relation has also been found between the severity of corrosion damage and the degree of tensile property degradation [2].

In this research experimental results show that the corrosion process alters the external surface of steel bar due to pitting, the residual cross section of the corroded bar is no longer round and varies considerably along its circumference and its length so the residual diameter is better defined by loss of weight. The rate of corrosion has been calculated by two terms, the term of mass loss rate (MR) and the term of penetration rate (CR). The mass loss rate decreased for fully coated bars by 1.7–2 times than half coated bars showing the importance of fully coating bars in corrosion repair. Finally, the reliability of using the galvanostatic method in research work was represented by comparing between the real--time and the accelerated time to reach a certain degree of corrosion [3].

The reinforcement corrosion is an electrochemical process that can be quantified by measuring the intensity of the current on the concrete surface. In this paper, to simulate the corrosion process, a current is externally applied to the studied structure reinforcement and then crack widths and vibration natural frequencies are measured. Based on these measurements a mathematical model is proposed to predict structure remaining life [4].

In this study, the electrochemical behavior of steel reinforced concrete was determined during the accelerated corrosion test. The suitability of this technique to chloride corrosion has been examined by examining the electrochemical nature of the test method. The corrosion of the rebar was applied by applying a constant anodic current of $100\mu A/cm^2$ to the prism. The electrochemical voltage of the steel was periodically monitored using a saturated calomel electrode on the concrete surface [5].

The impressed current technique also called the galvanostatic method consist of applying a constant current from a DC source to the steel embedded in concrete to induce significant corrosion in a short period of time. After applying the current for a given duration the degree of induced corrosion can be determined theoretically using faraday’s law or the percentage of actual amount of steel lost can be calculated with the help of a gravimetric test conducted on the extracted bars after subjecting them to accelerated corrosion [6].

In this study two groups of RC beams were degraded as a result of corrosion of steel bars.one group of beams were subjected to galvanometric method while the other group was corroded using the artificial climate environment. Comparative studies including the corroded characteristics of steel bar surface, the mechanical behavior of corroded bar and the load bearing capacity were conducted and obvious differences were found from the comparisons [7].

In another research the authors have recommended that the specimens under accelerated corrosion test using impressed current should be immersed in solutions containing chloride instead of pure water. They have reported that reinforcement corrosion in specimens under impressed current while immersed in chloride solution obeys faraday’s law. On the other hand they found that pure water is used a more complex process occurs during the accelerated corrosion test [8]

Research was done to evaluate the performance of reinforced concrete members incorporating supplementary cementitious materials such as fly ash, silica fume and slag against corrosion induced damage using the impressed corrosion technique [9].

According to previous research work a new method was developed to quickly assess the efficiency of corrosion inhibitors by electrically accelerating chloride ions diffusing on to the surface of the embedded steel bar in concrete and inducing corrosion. In order to obtain the corrosion rate of steel bar in different conditions potentiodynamic polarization scanning [10].

METHODOLOGY

The following Figure-1 shows the detailed methodology of this research starting from the tests on raw materials collected to the result analysis and discussion.

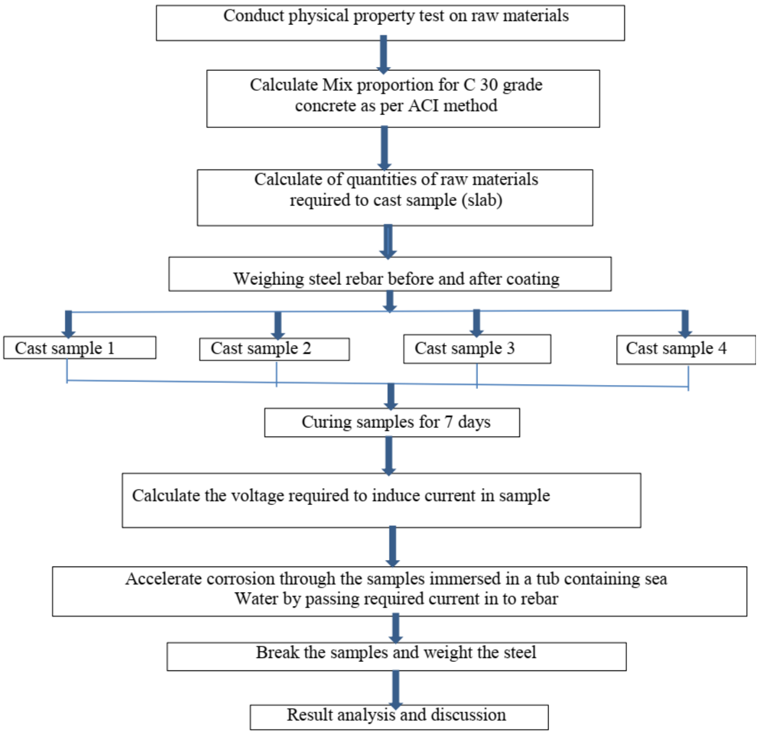

Figure 1: Detailed Methodology

Cement

Cement is the most important building material in the world and is a soft bonding material that hardens, thus possessing the joints and cohesion of the presence of water, which makes it able to connect the components of concrete to each other.

Fine Aggregates

In general, it consists of powdered rocks or natural sand, so that the granules of this total can pass through the sieve with openings under 5 mm diameter

Coarse Aggregates

It is the residual on a 5mm sieve, according to the approved standard, and contains the percentages allowed in this standard of coarse materials

Reinforcing steel

Reinforcement steel, or reinforcing bar, is a steel bar which is widely used in construction industry, especially for concrete reinforcement. Reinforcement is most commonly used as a tensioning device to enhance concrete and other construction structures to help hold concrete in a compressed state. In this study two types of rebar were used tor and mild steel. The length and diameter of both the rebar are 250 mm and 8 mm. The reinforcement cage has 4 bars on top and 3 bars in the bottom. The weight of mild steel and tor steel bars are observed before and after coating using an appropriate weighing machine

Mix Design Calculations for C30 Concrete Grade According to the American Concrete Institute

Mix design is the process of calculating mix proportion of various ingredients of materials such as cement, fine and coarse aggregate to achieve suitable strength in concrete. In this study, concrete mix design was done by using ACI method of mix proportioning following the steps given in Concrete Technology book [11].

For C30 grade concrete, the mix proportion for 1m3 of concrete mix is 1 : 1.67: 2.34 with W/C of 0.5. Mix design is the process of determine the properties of selecting amount of concrete depending on the ratios of cement, coarse and fine aggregate to achieve suitable strength in structure. Whole sentence can be deleted since it is repeating which is also mentioned as a reference. For C30 grade concrete, the following steps were followed in order to achieve the mix proportion.

Bulk volume of dry- rodded coarse aggregate per cubic meter of concrete from table 10.9 is 0.6 m^3.

Mass of coarse aggregate per cubic meter of concrete= 0.6 x density = 0.6 x 1600= 960 kg/m^3

Water cement ratio from table 10.12 = 0.54 and limited to 0.5 which is depending on the grade of concrete C30. Water content per meter cube of concrete for slump of 75 to 100mm and maximum size of aggregate is 20mm from table 10.11 = 205 kg.

Cement content = 205/0.5 = 410 kg/m^3.

For maximum size of aggregate of 20mm, the entrapped air content is 2.0%.

Fine aggregate content absolute volume of maximum ingredients per m^3:

Volume of cement= C/Sc= 410/ (3.15 x 1000) = 0.13m^3
Entrapped air = 2% = 2/100 = 0.020 m^3
Total = 0.725 m3
Hence, volume of fine aggregate required = 1 -- 0.725 = 0.275 m^3
Mass of fine aggregate = 0.275 × 2.5 × 1000 = 687.5 Kg
Mix ratio by mass:
Cement: Fine aggregate: Coarse aggregate
410:687.5: 960
1: 1.67: 2.34
Volume of concrete required:
(0.3 × 0.3 ×0.04) = 0.0036 m^3
For 4 slab = 0.0036 × 4 = 0.0144 m^3
Add for wasting 5% = 0.0144 × 0.05 = 7.2×10^{-4} m^3
Total volume = 0.015 m^3
Weight of cement required = 410 × 0.015 = 6.15 Kg
Weight of fine aggregate = 6.15 × 1.67 = 10.3 Kg
Weight of coarse Aggregate = 6.15 × 2.34 = 14.4 Kg

Preparation of concrete mix, casting of slab, curing and testing is carried at Caledonian College of Engineering at Material Testing Laboratory, Muscat. Figure 2 below shows the slab mould and steel rebar's which are used in this research. The reinforcement cage has four bars on top and three bars in the bottom.

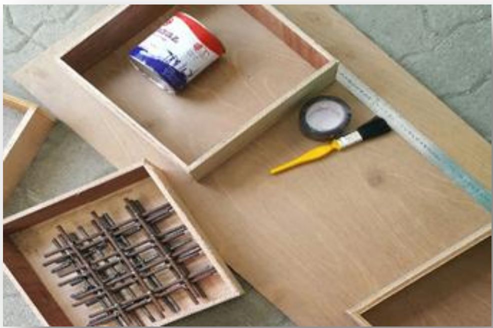

Fig-2: Slab moulds & steel rebar

Figure-3 below shows M-seal which is used to connect the wires with steel bars for accelerated corrosion process.

Fig-3: m-seal & Wire

The steel weight is measured before coating. After that paint rebar (2 mild + 2 tor) with protective coating as shown in Figure-4 then leave it for one day until the paint dries. After the paint is dry weigh it again and the wire is installed in the middle of the iron with m--seal and also left dry for one day. 4 rebar (2 mild + 2 tor) is left without a protective coating and the wire is installed in the middle of steel using m--seal

Fig-4: Steel with coating

The ingredients of concrete are weigh batched according to the mix ratio and the concrete mix is prepared for C30 grade as shown in Figure-5.

Fig-5: Prepare the concrete
(Source: CCE Lab)

Figure-6 below shows the four slab samples with mild and tor steel reinforcements (1 mild coated +1 uncoated mild +1 tor coated +1 tor uncoated) which will undergo the accelerated corrosion process.

Fig-6: Cast Slab Samples

The slab samples are removed from the mould and kept in a large tub filled with water for curing as shown in Figure-7.

Fig-7: Slabs before & during curing

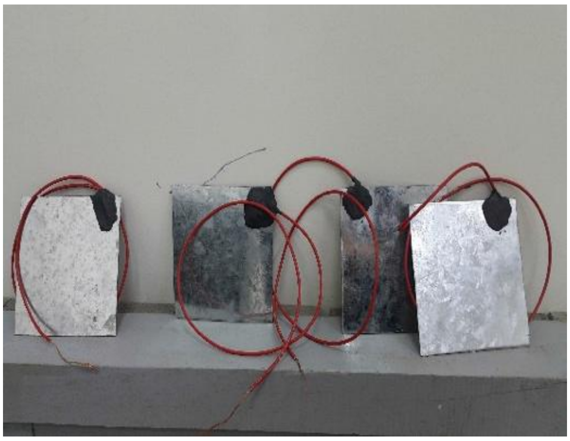

Fig-8: Stainless steel plate

Bring the stainless steel plate, drill a hole in one corner of plate and parte the wire with the help of m-seal, shown in Figure-8. Stainless steel plate will act as a cathode (-).

Fig-9: Corrosion acceleration

Two plastic tanks were used to immerse the slab specimen in sea water and a current of 0.8 A is supplied using a DC power supply equipment, shown in Figure-9 to accelerate the corrosion of steel rebar for a period of 5 days. The calculation of the power supplied to rebar is shown below.

Voltage Calculation

Current required to accelerate the corrosion process = 1.8 mA/sq.cm

7×250 mm $\times 25.13 = 37699.11$ mm^2 ($\pi \times 8 = 25.13$ mm)= 376.99 cm^2 = 377 cm^2

$=377 \times 1.8 = 678.6$ mA = 0.67 A = 0.8 A

Fig-10: Corrosion in process

Figure-10 shows the corrosion process of the slab sample. After the rebar is corroded to a certain extent the DC power supply can be switched off and the slab is removed out of the tub. The sample is demolished using a hammer to remove the rebar out in order to measure its weight. The same procedure is repeated for the next 3 samples with and without coating for both mild and tor steel bars.

RESULTS AND DISCUSSION

The discussion is based on the results obtained from various tests such as specific gravity, sieve analysis and water absorption test conducted on fine and coarse aggregates. The results of all the tests are given in Table-1.

Table-1: Physical property test results of raw materials

S. No	Name of Test	Result
1	Specific gravity of Fine Aggregate	2.6
2	Specific gravity of coarse aggregate	2.7
3	Fineness modulus of fine aggregate	4.2
4	Fineness modulus of coarse aggregate	6.9

From Table 1 it is observed that the specific gravity values of both fine and coarse aggregates are found to be within the standard range (2.5-2.9). Similarly the standard value of fineness modulus of fine aggregate is between 2.0 – 4.5 and for coarse aggregates the range is from 6.5 – 8.0 The weight of the mild steel and tor steel specimen have been observed before and after coating the specimen with zinc. In a similar manner the weight of the steel rebar's have been noted after accelerated corrosion process with and without coating for all the samples. Table-2 below shows the observations of all the samples used in this study. The accelerated corrosion test results indicate that the difference in weight of rebar before and after coating is negligible in case of both mild and tor steel specimens which was observed before inducing the required voltage through DC power supply. A similar trend is found while comparing the weights of mild and tor steel samples after passing 0.8 amperes of current in both the samples.

Table-2: Weight of specimens before and after corrosion process

Type of steel	Coating details	Initial weight before corrosion (Kg)	Final weight after corrosion (Kg)	Difference in weight (Kg)	Percentage reduction in weight due to accelerated corrosion
Mild steel	Without coating	0.66	0.55	0.11	17
	With coating	0.68	0.66	0.02	3
Tor steel	Without coating	0.69	0.495	0.195	28
	With coating	0.71	0.68	0.03	4

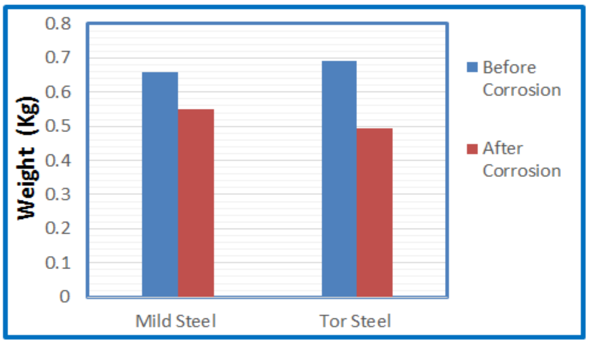

Fig-11: Weight of samples without protective coating

From Figure-11 it is observed that difference in weight of samples without coating before and after corrosion for slab containing mild steel rebar is around 110 grams with a weight reduction of nearly 17 percentage and for the tor steel rebar it is around 195 grams with 28 percent reduction in weight which indicates that tor steel rebar has corroded more than mild steel since the carbon content is higher in tor steel compared to the mild steel which accelerates more corrosion.

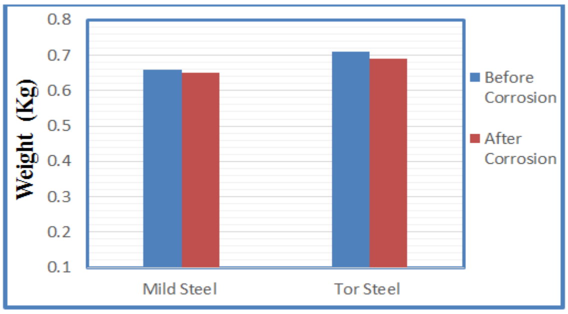

Fig-12: Weight of samples with protective coating

From Figure-12 it is evident that difference in weight of samples with coating before and after corrosion for slab samples is negligible with a weight reduction of 3 and 4 percentage for mild and tor steel respectively which shows that the zinc coating prevents corrosion of rebar's to a great extent irrespective of the specimens used in the research.

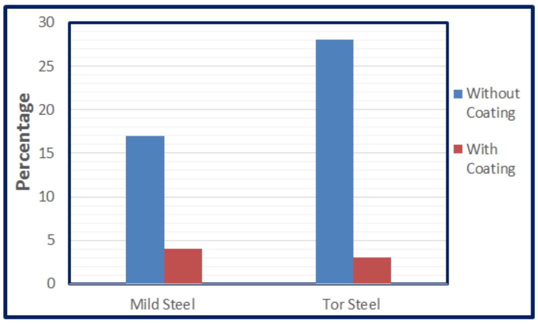

Fig-13: Percentage reduction in weight due to accelerated corrosion

From Figure-13 it can be observed that there is a variation of 13 percent of reduction in weight for mild steel sample with and without coating after corrosion. Moreover comparing the tor steel sample the variation is found to be 25 percent where the reduction in weight is 12 percent more than the mild steel sample.

Analyzing the percentage reduction in weight of both mild and tor steel samples the reduction in weight of tor steel rebar is 11 percent more compared to mild steel sample which is due to excess carbon content and saline water which enhances corrosion in the steel without coating. Similarly while comparing the percentage reduction in both the samples with coating the difference in weight is negligible since the protective coating tends to reduce the corrosion in steel using zinc without coating. Similarly while comparing the percentage reduction in both the samples with coating the difference in weight is negligible since the protective coating tends to reduce the impact of corrosion in steel. On the whole the above research reveals that steel rebar's with protective coating exhibits less corrosion compared to steel samples without coating using accelerated corrosion process.

CONCLUSION

- Comparing the weight of mild steel and tor steel specimen without coating the weight of tor steel is nearly 5 % more than the mild steel rebar.
- A percentage reduction in weight of nearly 17% is observed in mild steel specimen without coating while comparing the weight of specimen before and after corrosion.
- A percentage reduction in weight of nearly 28% is observed in tor steel specimen without coating while comparing the weight of specimen before and after corrosion.
- Comparing the final and initial weight of mild steel rebar (with coating) before and after corrosion process nearly 3% of reduction in weight is found which is negligible.
- Comparing the final and initial weight of tor steel rebar (with coating) before and after corrosion process nearly 4% of reduction in weight which found to be 25% higher than the mild steel specimen.
- Finally, the results reveal that samples with coating undergo less corrosion compared to samples without coating in both mild steel and tor steel specimen.

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