Effect of nano TiO$_2$-epoxy composite in bond strength and corrosion resistance of rebar embedded in micro-silica modified concrete

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Abstract. One of the significant drawbacks of RCC structures is Corrosion. It is a well-known term used to describe numerous interactions between a material and its surrounding environment resulting in degradation within the material properties. Reacting with ambient oxygen can cause the material to degrade by forming a more chemically stable form of oxides called Rust. A detailed literature study about the recent advances in the area of corrosion resistance of reinforced concrete has been done using nano-materials. Nano-materials can be deemed fit to be used in cement and concrete manufacture and have a wide range of applications in the civil industry. Compressive strength and ductility of concrete can be improved by blending Nano-materials in concrete. Leads to producing a very dense concrete and Decreases permeability of the concrete by micro filler effect. In the present study, nano-material is used in the preparation of coating material on the reinforcement bar. Higher opacity, the interaction between coating and surface, and higher durability of the coating can be achieved by adding nano-material. Different percentages of nano-TiO$_2$ (0.5%,1%,2%) mixed with epoxy are varied to find the percentage, which gives the least rate of Corrosion. For this purpose, the specimens coated with nano- TiO$_2$ epoxy composite are placed in two mediums such as 3.5% NaCl solution and 1M H$_2$SO$_4$ solution and studied the performance of corrosion resistance for every 15-day interval using LPR, Tafel plot and Electrical Impedance Spectroscopy(EIS).Characteristic properties like topography, composition, and surface morphology are studied using SEM, FTIR, and XRD analysis. To increase the mechanical properties of reinforced concrete, so industrial by-product micro-silica has been added to the cement mix. Reinforced cylindrical specimens were cast and were tested for bond strength. For micro-silica replaced concrete mix, destructive tests like compressive strength test and tensile strength tests were conducted.

Keywords: Corrosion, Micro-Silica, Nano-TiO$_2$, EIS and Rate of corrosion

1. Introduction

Concrete is strong in compression and very week in tension. Structural elements like beams, columns, and foundations should resist bending forces from the applied loads. Reinforcement bars or rebars are Reinforced in concrete to improve the tensile strength of the concrete. The coefficient of thermal expansion of concrete and mild Steel is almost equal, so during thermal expansion, it is one of the reasons for good bond strength. In the process of manufacture of reinforced bars, hot rolling is done within the mills, which involve giving it deformations on the surface leads to the formation of both longitudinal and transverse ribs so that it can form a good bond with concrete.

One of the significant drawbacks in the RCC structures that affect the durability of structures is corrosion. Environmental conditions (such as temperature, humidity, and chemical atmosphere) have
more influence on the metal. It is the natural process. So, when various RCC structures exposed to salts, chemicals, or moisture resulting in the formation of more stable compounds such as oxides, sulphide or hydroxides from metals. It is the step by step damaging of materials (usual metals) by both electrochemical and chemical reactions with the surrounding environment. Loss of metal in designed structural members leads to an increase in the tensile load on the existing metal resulting in faster deteriorations or decreasing the service life of a structure, and concrete begins to crack and spall due to swelling. They are three mass transport processes, such as oxygen diffusion, carbonation, and chloride ion diffusion, for determining the Corrosion of Reinforcing Steel in concrete.

There are six general types of corrosion they are Uniform, Pitting, crevice, intergranular, stress corrosion cracking and, galvanic. Among all kinds of corrosion, pitting corrosion considered to be more dangerous than uniform corrosion as it is hard to predict, detect, and protect. It is caused by penetration of chlorine into RCC structures from surrounding environment and damaging the passive film, so pitting corrosion occurs at oxide breaks Factors influencing Corrosion are Severity of exposure, carbonation of concrete, Quality of construction material, Ambient temperature, Relative humidity, cover to reinforcement and Formation of cracks. The following review of earlier investigations for improving corrosion resistance of steel rebars in concrete can be classified mainly into 4 categories: (a)Replacement of cement[1],[1],[2],[3],[4],[12]; (b)Replacement of Fine Aggregate or Coarse Aggregate[1], (c)Protective Coating and corrosion inhibitors[5],[6][d)Addition of chemical admixtures[7].

Micro-silica is a mineral that improves the corrosion protection and strength of concrete by reducing the permeability of the concrete and forming more calcium silicate hydrate (CSH) which provides strength and durability to Concrete [4]. When silica is replaced by cement up to 20%, it can alter its attributes. Field tests indicate that adding micro silica increases resistance to abrasion, reinforcement corrosion, sulphate and chemical. Compressive strength, consistency and mechanical performances are increased while permeability and heat reduced.[8] Bhatt et al [9] infers that cement replacement up to 10% with silica fume leads to increase in compressive strength, for M30 grade of concrete. From 15% there is a decrease in compressive strength for 3, 7, 14- and 28-days curing period. As it is showing good results for resistance of corrosion 10% replacement to cement is incorporated in the present study.

Epoxy coated rebar is designed to protect the rebar against rust and corrosion. Applying an epoxy coating to steel rebar prevents oxygen and chlorides from reaching the steel surface reducing corrosion. Nanomaterials are known for their outstanding mechanical and physical properties due to their extremely fine grain size and high grain boundary volume fraction. Titanium dioxide (TiO₂) nanomaterials are known for their numerous and diverse applications, which range from common products such as sunscreens, to advanced devices [10]. Similar applications are also shown in corrosion resistance of the reinforced concrete structure[11]. The unique characteristics of nanocomposite coatings include enhanced mechanical strength, weight reduction, improved barrier properties, and increased heat, wear, and scratch resistance for lifelong performance. Coatings the composite coatings containing nanoparticles like carbon nanotubes, nanosized carbon paste, nanoparticles of TiO₂, Zn, silica, ceramic powders, Fe₂O₃ are gaining importance due to their corrosion resistance properties. Some of the available nanomaterials were taken, and characteristic study of nanomaterials is done.

2. Materials and their properties:

2.1 Cement

Ordinary Portland Cement of Dalmia brand-53 grade confirming to IS: 12269-2013 is used in the present study. Tests were conducted to find the properties of the Dalmia OPC-53 grade as per IS codes. Specific gravity of cement used is 3.06 and consistency of the cement is 33%. The mentioned results are checked with the values mentioned in IS12269: 2013 and found to be correct.
2.2 Micro silica
It is one of the industrial powdered by-products in the manufacture of silicon and ferrosilicon alloy. It can also be named as silica fume, which is an amorphous polymorph of silicon dioxide, silica. In the present study, the micro-silica used was from Astraa chemicals manufactures. In Table 1 and Table 2 the specifications and properties of 10% replacement to cement is mentioned.

| Specification of Micro silica | Properties of Micro silica |
|-----------------------------|---------------------------|
| Colour                      | Name of the test           |
| White                       | Specific gravity           |
| State                       | Consistency                |
| Powdered                    | Initial setting time       |
| Density                     | Final setting time         |
| 0.76 gm/ cc                 | 1hr5min                    |
| pH                          | 6hr25min                   |
| 6.90                        |                           |
| Specific gravity            |                           |
| 2.51                        |                           |

2.3 Coarse aggregate
Crushed aggregate confirming to IS: 383-1987 is used in this project. The aggregate passed through 40mm and retained on 4.75mm. Specific gravity of Coarse aggregate used is 2.90, Fineness modulus is 7.90 and water absorption is 0.41%. The mentioned results are checked with the values mentioned in IS383 and found to be correct.

2.4 Fine aggregate
Crushed sand confirming to IS:383-1987 is used in this study. Crush sand has a property the same as that of river sand containing no organic impurity, so it increases the strength of concrete with the same cement content. The aggregate passes through 4.75mm and retained on 150 microns is used. In Table 3 Some of the properties of the aggregates are mentioned.

| Properties of Fine aggregate | Specification of Nano-TiO2 |
|------------------------------|---------------------------|
| Name of the test             | Specification             |
| Specific gravity             | Average particle size     |
| Particlesize distribution    | 30-50nm                   |
| Fineness modulus             | Specific surface area     |
| Water absorption Test        | 200-230 m²/g              |
|                              | Atomic weight             |
|                              | 79.865g/mol               |
|                              | Bulk Density              |
|                              | 0.15-0.25 g/cm³           |
|                              | True density              |
|                              | 4.23 g/cm³                |

2.5 Nano-TiO2
It is one of the non-toxic materials, which is chemically stable, biocompatible, and a strong oxidizing agent has very high photocatalytic activity. In the present study, Nano-TiO2 used was from Platonic Nano-Tech Private Limited. In Table 4, the details and material properties of the Nanomaterial are mentioned.

2.6 Epoxy Resin and Hardener
Epoxy resin possess most desirable properties for civil engineering applications. It has high adhesive strength to almost all materials, low shrinkage during curing, good thermosetting properties and resistant to most chemicals and environments. In the present study Epoxy Resin of grade LY556 and Hardener of grade HY951 is used.

2.7 Steel Reinforcement bars
In the process of manufacture of reinforced bars, hot rolling is done within the mills, which involve giving it deformations on the surface leads to the formation of both longitudinal and transverse ribs so that it can form a good bond with concrete. In this project Steel reinforcement Fe-500 grade is used to evaluate the rate of corrosion. From the stress-strain curve, we can establish the various characteristics
of rebar under different stress conditions. The stress-strain curve helps to identify the ultimate strength of rebar the value is 530Mpa.

3. Experimental program:

3.1. Design mix:
Concrete Mix design is the process of finding the right proportions of Cement, Coarse aggregate, Fine aggregate and Water. The concrete mix design states the ratio of Cement: FA: CA. The mix design of M25 grade concrete for control specimen is 1: 3: 1.7. The mix design of M25 grade concrete with 10% replacement micro silica for specimens is 1: 2.7: 1.5. The process of finding the right proportions of standard concrete and silica blended concrete are almost the same. In Figure 1 and Figure 2 Quantities required per cubic m is represented in pie diagram for two different mixes.

3.2. Compression strength:
Compressive strength is the one of the important properties of the concrete. When a material subjected to compression load results to change in the dimensions (reduces its size), while in tension, size elongates.

\[
\text{Compressive strength of the specimen} = \frac{\text{Load applied at point of failure}}{\text{Cross sectional Area of the face}}
\]

Compression test of the two different mixes are founded by casting 3 cubes for each mix. These specimens are tested by compression testing machine after 28 days curing. The specimens are tested in UTM and Load should be applied gradually at the rate of 140 kg/cm² per minute till the specimens fails in Universal testing machine.

3.2.1. Result:

Table 5, As per code average of the three values shall be taken as the representative of the batch and the individual variation is not more than +/- 15 percentage of the average. It is found from the experiment that the 10% Micro silica replacement cement M25 design mix has shown higher Average compressive strength than M25 design mix(Figure 3) that is 25.6% more than the Control specimen.
Figure 3. Graphs representing compressive and tensile strength of all specimens

Table 5. Compressive strength of cube specimens

| SI No. | Age in days | Load (kN) | Compressive strength (N/mm²) | Average Compressive Strength (N/mm²) | Variation (%) |
|--------|-------------|-----------|------------------------------|-------------------------------------|--------------|
| 1      | 28          | 600       | 26.7                         | 26.9                                | 1.0%         |
| 2      | 28          | 630       | 28.0                         | -                                   | -3.7%        |
| 3      | 28          | 580       | 25.8                         | 4.5%                                |              |
| 4      | 28          | 615       | 27.3                         | -1.4%                               |              |
| 5      | 28          | 750       | 33.3                         | 0.8%                                |              |
| 6      | 28          | 810       | 36.0                         | -6.5%                               |              |
| 7      | 28          | 710       | 31.6                         | 6.5%                                |              |

Table 6. Splitting tensile strength of cylinder specimens

| SI No. | Age in days | Load (KN) | Tensile strength (N/mm²) | Average Tensile Strength (N/mm²) | Variation |
|--------|-------------|-----------|--------------------------|----------------------------------|-----------|
| 1      | 28          | 275       | 3.9                      | 3.7                              | -4.81     |
| 2      | 28          | 250       | 3.5                      | 4.1                              | 5.71      |
| 3      | 28          | 260       | 3.7                      | 4.1                              | 0         |
| 4      | 28          | 295       | 4.17                     | 4.1                              | -2.96     |
| 5      | 28          | 280       | 3.96                     | 4.1                              | 2.22      |
| 6      | 28          | 285       | 4.0                      | 4.1                              | 0.49      |

3.3 Splitting Tensile Strength:

Tensile strength is one of the properties of concrete used in design of many concrete structures. Splitting Tensile Strength of the two different mixes are founded by casting 3 cylinders for each mix.

\[
Tensile \ strength = \frac{2 \times P}{\pi \times D \times L}
\]

P is Maximum load indicated by testing machine, D is diameter of the specimen is 150mm, L is length of the specimen is 300mm long. Plywood strip is placed on the lower plate and place the specimen. Align the specimen so that the lines marked on the ends are vertical and centred over the bottom plate. Place the other plywood strip above the specimen. Bring down the upper plate so that it just touches the plywood strip. Apply the load continuously without shock at a rate within the range 0.7 to 1.4 MPa/min. Finally, note down the breaking load P.

3.3.1. Result:

Table 6, As per code average of the three values shall be taken as the representative of the batch and the individual variation is not more than +/- 15 percentage of the average. It is found from the
experiment that the 10% Micro silica replacement cement M25 design mix has shown higher Average Tensile strength than M25 design mix (Figure 3) that is 10.8% more than the Control specimen

3.4 Rate of corrosion:
To find the optimum percentage of TiO₂ in the Epoxy Resin. The Percentage of TiO₂ is varied and total of 3 % different percentages such as 0.5%, 1% and 2% is studied. The details of the specimen are mentioned in Table 7 and the No of rebars used in the study is mentioned in Table 8.

Table 7. Trail -1 specification

| Specifications      | Trail-1 |
|---------------------|---------|
| Length of Rod       | 15cm    |
| No of mediums       | 2       |
| Medium 1            | 3.5% NaCl|
| Medium 2            | 1 M H2SO₄|

Table 8. Total No of rebars

| Reinforcement bars  | 3.5% NaCl | 1M H2SO₄ |
|---------------------|-----------|----------|
| Bare rods           | 2         | 2        |
| Coated with Epoxy   | 2         | 2        |
| Coated with Epoxy +%| 2         | 2        |
| Coated with Epoxy +%| 2         | 2        |
| Coated with Epoxy +%| 2         | 2        |
| Total               | 10        | 10       |

3.5. Specimen Specification
3.5.1. Trail-1-(0%, 0.5%, 1%, 2%)
20 number of 12mm diameter and 15cm length reinforcement bars were cut and were initial cleaning by both chemical and physical methods. After initial preparation the rods were cleaned with Acetone before applying coating. The given percentages of nano-TiO₂ were added to Epoxy and were sonicated for a period of 45 min and for 2% Nano-TiO₂ in epoxy were sonicated for 70 min. The reason for increasing the period of sonication is there are some of the Parameters like 1) Time of Sonication, to get uniform dispersion of nano-TiO₂ in the Epoxy resin. 2) Amount of hardener to be added in the epoxy to get a workable mix for Dip coating. 3) Temperature for drying the coating. Prior to the preparation of the Nano-TiO₂ and Epoxy mix, To get the Uniform Dispersion the sonication time was varied from 0 to 120 min. it is found that for the lower percentages the total mixing time of 45 min and for the higher percentages above 1.5% of Nano-TiO₂ in Epoxy the total mixing time of 70 min is adopted (Figure 4). TiO₂ Nano particles are mostly circular in shape and size varies from 30nm-50nm. Van Der Waal force between the particles is leading reason for weak dispersion which leads to agglomeration. Smaller size has more Van Der Waal force between the particles and that decrease the dispersion capability of the TiO₂ nanoparticles in the epoxy. The particle–particle interaction is high for smaller size. The applied ultrasonic energy and time of dispersion are unable to separate all particles for higher percentages.

Figure 4. Visual inspection of rebars coated with 0.5%, 1% and 2% (trail-1 & trail-2) Nano TiO₂ epoxy composite

All the Durability tests are carried out in an Air-Conditioned room at 20° centigrade. The tests that conducted, Linear Polarisation Resistance (LPR) and Tafel plot using SP:300. The information
obtained from both values is necessary to study the corrosion state of system. The outputs from the experiment are $I_{\text{corr}}$, Rate of corrosion and $R_P$.

A three-electrode setup is must to carry out electrochemical tests. The three-electrode setup consists of Saturated Calomel electrode as reference electrode because it has a pre-determined voltage which helps in measuring the voltage of the specimen and the rebar itself is a working electrode[13]. While conducting experiment the specimens are partially immersed in the respective medium up to three fourth of the height of the specimen. If the specimens are immersed completely there is a chance of lack of oxygen and may cause concentration polarisation. Both the reference electrode and counter electrode are immersed in water. The Experimental setup is shown in Figure 5 Prior to the Tafel and Rp fit. The open circuit potential should be stabilized, such that the deviation of the $E_{\text{corr}}$ values are not varying for a 60s period of time.

![Figure 5. Experimental setup for finding Rate of corrosion](image)

**Figure 5.** Experimental setup for finding Rate of corrosion

### 3.5.2. Tafel Fit

The Stern relation can be written as followed:

$$I = I_{\text{corr}} \left[ \exp \left( \log \frac{10}{\beta_a} \left( E - E_{\text{corr}} \right) \right) - \exp \left( \log \frac{10}{\beta_c} \left( E - E_{\text{corr}} \right) \right) \right]$$

It can be used for a wide range of $\Delta E$ ranging ±200 mV. In this technique we can directly calculate rate of corrosion directly by using the equation. The rest period $t_R$ is set for 30 seconds and $dE/dT$ is set to 5 mV/s. From the graph displaying log |I| vs. $E_{\text{WE}}$, it is possible to determine the values of $I_{\text{corr}}$, $E_{\text{corr}}$, $\beta_a$ and $\beta_c$ by a simple analysis. where $\beta_a$ and $\beta_c$ are the anodic and cathodic Tafel slopes. The Tafel fit, which is a Graph Analysis tool from EC-Lab, can determine automatically these values. The input parameters to find the rate of corrosion is shown in Figure 6 ($d = \text{density in g/cm}^3 = 7.86 \text{ g/cm}^3, A = \text{surface area of the steel rod}, E_{\text{WE}} = \text{equivalent weight in g/equivalent} = 27.92 \text{ g/equivalent.}$ $I_{\text{corr}}$= Corrosion Current)

![Figure 6. Input Parameters for Rp and Tafel fit](image)
3.5.3. $R_p$ Fit
The most used technique to evaluate corrosion current $I_{corr}$ is Linear Polarisation resistance. It is also used to calculate rate of corrosion using Stern-Geary equation.

$$I_{corr} = \frac{\beta_a \beta_c}{R_p (\beta_a + \beta_c) \ln 10}$$

$R_p$ can be obtained from the slope of polarisation curve.

$$R_p = \frac{1}{(dI/dE)}$$

In linear polarisation resistance the value of $\Delta E$ is limited to $\pm 25$ mV. The input parameters for LPR and Tafel plot are shown in Figure 6. A graph is drawn between $I$(mA) VS $E$(V). The corrosion current $I_{corr}$ is calculated for the corresponding $E_{corr}$ value. More the value of $R_p$ resistance to resist corrosion is more and vice-versa.

3.6. Rate of corrosion from SP-300
To accelerate or initiate the corrosion in the Coated rebars. Coated rebars are exposure to two different mediums namely 3.5%NaCl Medium[6] it also known as severe marine medium and 1M H$_2$SO$_4$.

3.6.1. Trail-1 in 3.5%NaCl medium:
The trial specimens (0.5%,1%,2%, epoxy, bare rod) were kept in 2 mediums: 3.5% NaCl solution and 1M H$_2$SO$_4$ solution. The 0$th$ day, 5$th$ day, 20$th$ day and 35$th$ day readings for the rate of corrosion and polarization resistance were taken using the EC lab software and EIS sp300 device. The results are shown in the Table 9, Table 10, Table 11, Table 12, Table 13,Table 14 and Table 15:

From the obtained results it can be inferred that 1% addition of nano-TiO$_2$ gives the most resistance to corrosion and the least rate of corrosion, in the 3.5% NaCl medium. (Figure 7)

3.6.2. Trail-1 in 1M H$_2$SO$_4$ medium:
From the obtained results, it can be inferred that 1% addition of nano-TiO$_2$ gives the most resistance to corrosion and the least rate of corrosion, in the 1M H$_2$SO$_4$ medium (Figure 8)

| Percentage of Ti02 | corrosion rate (mpy) | Rp (ohm) | $E_{corrosion}$ | $I_{corrosion}$ |
|-------------------|----------------------|----------|----------------|-----------------|
| 2%                | 0.4716               | 450      | -620.332       | 78.4291         |
| 1%                | 0.8466               | 261      | -587.578       | 135.464         |
| 0.50%             | 0.5120               | 294      | -609.937       | 120.03          |
| Epoxy             | 1.0628               | 217      | -532.685       | 162.145         |
| Bare Rod          | 1.6117               | 83.4     | -735.822       | 423.5           |

Table 9.Tail-1 Rate of corrosion on 0th day in 3.5% Nacl medium

| Percentage of Ti02 | corrosion rate (mpy) | Rp (ohm) | $E_{corrosion}$ | $I_{corrosion}$ |
|-------------------|----------------------|----------|----------------|-----------------|
| 2%                | 0.83558              | 148      | -627.902       | 239.278         |
| 1%                | 1.15789              | 136      | -642.247       | 258.998         |
| 0.50%             | 0.81616              | 185      | -633.067       | 191.321         |
| Epoxy             | 1.01953              | 148      | -725.196       | 238.379         |
| Bare Rod          | 7.39073              | 26.3     | -608.635       | 1340.65         |

Table 10.Tail-1 Rate of corrosion on 5th day in 3.5% Nacl medium
### Table 11. Trail-1 Rate of corrosion on 35th day in 3.5% NaCl medium

| Percentage of TiO₂ | Corrosion rate (mpy) | Rp (ohm) | E corrosion | I corrosion |
|--------------------|-----------------------|----------|-------------|-------------|
| 2%                 | 22.248                | 20.2     | -595.934    | 1748.94     |
| 1%                 | 19.969                | 22.9     | -441.068    | 1544.78     |
| 0.50%              | 24.671                | 6.4      | -606.775    | 5515.93     |
| Epoxy              | 30.706                | 17.9     | -644.775    | 1977.77     |
| Bare Rod           | 36.741                | 5.02     | -749.968    | 7028.807    |

### Table 12. Trail-1 Rate of corrosion on 0th day in 1M H₂SO₄ medium

| Percentage of TiO₂ | Corrosion rate (mpy) | Rp (ohm) | E corrosion | I corrosion |
|--------------------|-----------------------|----------|-------------|-------------|
| 2%                 | 31.4691               | 4.83     | -447.837    | 7303.37     |
| 1%                 | 34.0512               | 3.65     | -454.18     | 9660.07     |
| 0.50%              | 38.5132               | 7.73     | -462.728    | 4568.58     |
| Epoxy              | 33.5218               | 7.87     | -466.571    | 4485.19     |
| Bare Rod           | 40.4079               | 2.33     | -437.971    | 15155.9     |

### Table 13. Trail-1 Rate of corrosion on 5th day in 1M H₂SO₄ medium

| Percentage of TiO₂ | Corrosion rate (mpy) | Rp (ohm) | E corrosion | I corrosion |
|--------------------|-----------------------|----------|-------------|-------------|
| 2%                 | 302.74                | 1.06     | -563.33     | 33160.8     |
| 1%                 | 328.35                | 1.01     | -541.962    | 34809.3     |
| 0.50%              | 325.99                | 1.01     | -541.962    | 34809.3     |
| Epoxy              | 295.00                | 1.5      | -562.502    | 23584.4     |
| Bare Rod           | 340.52                | 1.28     | -516.502    | 35754.2     |

### Table 14. Trail-1 Rate of corrosion on 20th day in 1M H₂SO₄ medium

| Percentage of TiO₂ | Corrosion rate (mpy) | Rp (ohm) | E corrosion | I corrosion |
|--------------------|-----------------------|----------|-------------|-------------|
| 2%                 | 58.81                 | 3.6      | -691.988    | 9815.11     |
| 1%                 | 53.92                 | 2.51     | -708.835    | 14054.3     |
| 0.50%              | 51.91                 | 2.92     | -709.241    | 12090       |
| Epoxy              | 62.67                 | 2.43     | -708.603    | 14524.7     |
| Bare Rod           | 67.06                 | 4.34     | -620.727    | 8140.7      |

### Table 15. Trail-1 Rate of corrosion on 35th day in 1M H₂SO₄ medium

| Percentage of TiO₂ | Corrosion rate (mpy) | Rp (ohm) | E corrosion | I corrosion |
|--------------------|-----------------------|----------|-------------|-------------|
| 2%                 | 124.751               | 1.98     | -683.073    | 17860       |
| 1%                 | 170.86                | 1.52     | -655.28     | 23305.5     |
| 0.50%              | 106.78                | 2.37     | -657.45     | 14867.54    |
| Epoxy              | 65.63                 | 3.98     | -623        | 8877.95     |
| Bare Rod           | 29.71                 | 8.25     | -602.8      | 4278.24     |
Figure 7. Trail-1 Bar chart showing rate of corrosion in 3.5%NaCl medium

Figure 8. Trail-1 Bar chart showing rate of corrosion in 1M H$_2$SO$_4$ medium

Table 16. Data Table for Bond Strength

| Coating          | Type of mix               | Load at failure(kN) | Bond strength (N/mm$^2$) | Average (N/mm$^2$) |
|------------------|---------------------------|---------------------|--------------------------|-------------------|
| **Bare Rod-1**   | 10% silica blended concrete | 48.30               | 9.78                     | 8.50              |
|                  |                           | 47.90               | 8.47                     |                   |
| **Epoxy**        | 10% silica blended concrete | 46                  | 8.13                     | 8.4               |
|                  |                           | 49                  | 8.66                     |                   |
| **Epoxy+0.5%**   | 10% silica blended concrete | 46.80              | 8.27                     | 8.51              |
|                  |                           | 49.49               | 8.75                     |                   |
| **Epoxy+1%**     | 10% silica blended concrete | 60.80             | 10.75                    | 10.5              |
|                  |                           | 58.97               | 10.42                    |                   |
| **Epoxy+2%**     | 10% silica blended concrete | 47.5               | 9.39                     | 9.61              |
|                  |                           | 50.4                | 9.83                     |                   |

3.7 Bond strength

The cross section of specimens for pull-out experiment is a cylinder of cross section 300mm height, 150 mm diameter and a rebar is embedded at the centre of cylinder with an embedded length of 150mm [14]. Experimental setup as shown in Figure 9. The rebars coated with different percentage of Epoxy-NanoTiO$_2$ and are founded by casting 10 cylinders. The mix design of M25 grade concrete with 10% replacement micro-silica for ten specimens is 1: 2.7: 1.5. These specimens are tested by Universal Testing Machine for Bond Strength after 28 days curing (Table 16). It is found from the experiment that Epoxy with 1% nano TiO$_2$ have Highest Average bond strength (Figure 10) and with the increase in percentage of TiO$_2$ in Epoxy for coating increases the Bond Strength.
4. Conclusion:
The following conclusions are been drawn upon based on the studies taken in the project:

1. The compressive strength of the micro silica replaced concrete showed more compressive strength than the control specimen. It is found from the experiment that the 10% micro silica replacement cement M25 design mix has shown higher average compressive strength than M25 design mix that is 25.6% more than the control specimen.

2. The tensile strength of the micro-Silica replaced concrete showed more splitting tensile strength than the control specimen. It is found from the experiment that the 10% Micro silica replacement cement M25 design mix has shown higher Average Tensile strength than M25 design mix that is 10.8% more than the Control specimen.

3. 1% addition of nano-TiO₂ gives the most resistance to corrosion and the least rate of corrosion, in the 3.5% NaCl medium, from the values incurred from the trial-1 specimens.

4. 1% addition of nano-TiO₂ gives the most resistance to corrosion and the least rate of corrosion, in the 1M H₂SO₄ medium, from the values incurred from the trial-1 specimens.

5. The bond strength between the reference specimen and the specimens with an epoxy- nano-TiO₂ composite coating do not vary much and are considered to be safe for usage.

Therefore, 1% addition of TiO₂ to the epoxy resin and giving a composite coating of epoxy-nano-TiO₂ to the steel rebars, along with 10% replacement of micro silica with cement, gives the most desirable reinforced concrete mix. It inhibits the rate of corrosion and also improves mechanical properties such as compressive and tensile strength.

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