

Study on Effect of Corrosion in Blended Cements

Remya R S¹, Vishnumaya K V², Tisny D B³

Department of Civil Engineering, Mohandas College of Engineering and Technology, Thiruvananthapuram, Kerala, India

Department of Civil Engineering, Mar Baselios College of Engineering and Technology, Thiruvananthapuram, Kerala, India

ABSTRACT: Corrosion of reinforcing steel is one of the most important causes of deterioration of concrete structures all around the world and especially in coastal environment. Steel and other ferrous material along the coastal line are susceptible to corrosion which is mainly initiated by chloride ions present in the sea salts. High permeability concrete, poor design detailing and construction defects can lead to the ingress of salt and moisture into the concrete. Level of corrosion was assessed in quantifiable terms and the effects are correlated with the engineering properties of structural elements. The effect of corrosion on concrete was studied using different types of rebars. Strength tests and corrosion tests were conducted on blended cements (PPC & PSC). The results inferred that PPC has more strength as compared to PSC. Both PPC and PSC have comparatively higher strength and resistance to corrosion with respect to OPC.

KEYWORDS: corrosion, Weight loss method, Calomel Electrode, Tafel Extrapolation Techniques, OPC, PPC & PSC

I. INTRODUCTION

Reinforced concrete is a versatile, economical and successful construction material. The corrosion of reinforcing steel in concrete is a major problem facing civil engineers and surveyors today as they maintain an ageing infrastructure. The economic loss and damage caused by the corrosion of steel in concrete is arguably the largest single infrastructure problem facing industrialized countries. Steel and other ferrous metal along the coastline are susceptible to corrosion, which is mainly initiated by chloride ions present in the sea salts. It is further sustained by the oxygen present in the atmosphere, which diffuses through to the surface of the metal. Corrosion of rebar embedded in concrete is one of the foremost factors that affect the durability and serviceability of concrete structures in marine environments. To simulate marine substructure condition in the laboratory, studies were made on by forming chloride ion concentration gradient in concrete, which accelerated the corrosion. The assessment of the loss of serviceability of reinforced concrete is made on the basis of models or the measurement of corrosion rates. The corrosion study will be conducted using different types of cement (OPC, PPC & PSC) and the most corrosion resistant and durable type will be determined after 28 days, using different methods such as Weight Loss, Calomel Electrode & Tafel Extrapolation Techniques and compressive strength tests. The study can be extended to find the corrosion resistivity of Self-healing Concrete, Recycled Concrete and Fibre reinforced Concrete in future.

II. OBJECTIVES

- To conduct a comparative study on the effect of corrosion in blended cements.
- To determine the corrosion of steel reinforcement, compressive strength, modulus of elasticity and loss of serviceability (based on flexural strength in beams).
- It also examines the influence of PSC on the rate of reinforcement corrosion.
- The experimental study conducted to develop numerical models to predict: (a) Rate of corrosion (b) Serviceability loss from corrosion rate in beams.

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III. LITERATURE REVIEW

Bong SeokJang, Byung Hwan Oh (2010) studied the effects of non-uniform corrosion distribution, cover-to-rebar diameter ratio, and concrete compressive strength on the cracking pressure of concrete cover. The study indicates that the pressures to cause cracking of concrete cover under non-uniform corrosion conditions are much smaller than those under uniform corrosion case. HuiYu, Xianming Shi, William H. Hartt, Baotong Lu (2010) studied the Time-to-corrosion (Ti) of reinforcement in concrete and chloride threshold content (Cth) are important service life determinants for reinforced concrete structures in chloride-laden environments. The results indicate that the corrosion initiation of rebar in concrete slabs depends upon both cement alkalinity and superplasticizer.

VeluSaraswathy, Ha-Won Song (2007) Pozzolana Portland cement (PPC) and 25% fly ash replaced in ordinary Portland cement (FA) by designing two grades of concrete, M20 and M40 mixes under accelerated exposure conditions. Reinforced concrete slabs of size 900mm×180mm×100mm were cast, cured and pre-cracked to crack width of 0mm and 0.10 mm, exposed to accelerated testing conditions in 3% NaCl environments and evaluated for their corrosion resistance.

IV. METHODOLOGY

The laboratory data is to be used to develop numerical models to predict: a) rate of corrosion, b) serviceability loss from corrosion rate (using beams). Concretes having aggregate water-cement ratios (1:1.5:3) are to be produced by using a plain and blended Portland cements. Concrete specimens are to be subjected to wet curing. The compressive strength and corrosion resistance of the concretes are to be determined at different ages up to 28 days. The initial testing specimens are prepared using ordinary Portland cement, natural aggregate and Tor steel. Another set of specimens are prepared by replacing ordinary Portland cement with PPC and PSC. Using different types of cement the effect of corrosion on various types of concrete were studied. The effect of corrosion will be induced in the above samples by adding NaCl solution. 20,000 ppm of NaCl solution should be ponded over the specimen for 28 days.

V. EXPERIMENTAL INVESTIGATION

The materials used in the study were Cement, Fine aggregates, coarse aggregates, reinforcement bars, steel plates and wires for passing current. Primary laboratory tests include tests on cement, particle size analysis, chemical analysis etc. The amount of Corrosion rate can be studied using Weight loss method, Calomel Electrode, Tafel Extrapolation Techniques. The tests on the uncorroded samples and the samples subjected to accelerated corrosion should be repeated on 28th day.

The specimens to be prepared are 15cm x 15cm x 15cm concrete cubes, cylindrical specimens of 15cm diameter, 30cm long, 50cm x 10cm x 10cm beams (for conducting flexural strength test) and beams of size 70cm x 15cm×15cm (load deflection study) using ordinary Portland cement, natural aggregate and mild steel. Another set of specimens are prepared by replacing Ordinary Portland cement with Portland Pozzolanic Cement and Portland Slag Cement. Specimens are also to be prepared using reinforcements for corrosion study.

Tests on fresh concrete and hardened concrete are done. Compressive strength of concrete is tested on cubes of size 150mm×150mm×150mm, that was prepared with OPC, PPC & PSC at the age of 28 days as per IS 516:1959. Compressive strength tests on 150mm×300mm cylinders were carried on 28 days cured specimens as per IS specifications using Universal Testing Machine. Six specimens from each type of cement were considered for testing.

A. FLEXURAL STRENGTH TEST

Tests were carried out on 100mmx100mmx500mm beams conforming IS 516:1959 to obtain the flexural strength for the designed concrete mix at the age of 28 days. Strength tests were also carried out on reinforced beams to obtain the load deflection relation for different types of cement at the age of 28 days

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The values of stress and strain for OPC and PPC are found out. The graphical representation of modulus of elasticity for various type of cement is shown in Figure1. To be able to calculate the deformation and deflection of structural members, we have to know the relation between stress and strain.

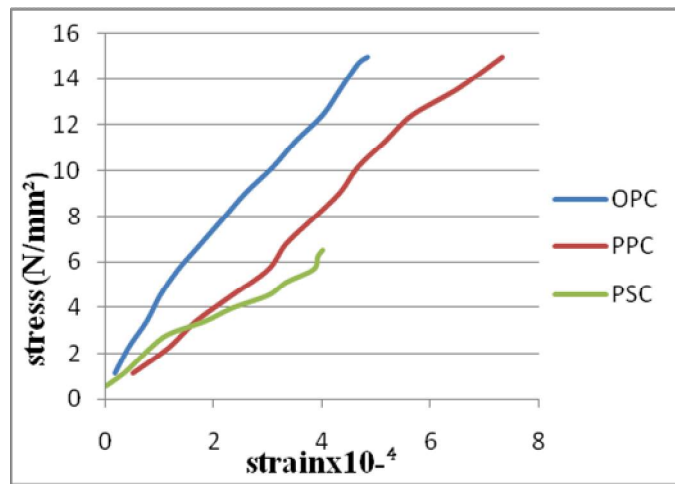


Fig. 1. Stress – Strain graph for OPC, PPC & PSC

B. SPLITTING TENSILE STRENGTH TEST

In the splitting test, a concrete cylinder is placed with its axis horizontal, between platens of a testing machine, and the load is increased until failure takes place by splitting in the plane containing the vertical diameter of the specimen. The splitting test is simple to perform and gives more uniform results than other tension tests. The strength determined in the splitting test is believed to be closer to the true tensile strength of concrete compared to the other tests conducted.

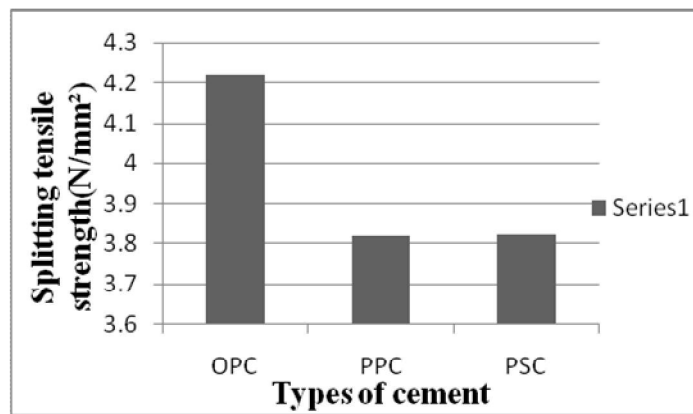


Fig. 2. Variation of Splitting tensile strength for various types of cement

C. STRENGTH TEST ON REINFORCED BEAM

The strength test was conducted on beams of size 150x150x700mm size on six specimens each of OPC, PPC and PSC. The test was conducted using 10mm dia bars for OPC and 8mm dia bars for PPC and PSC. The results are shown in Figure 3.

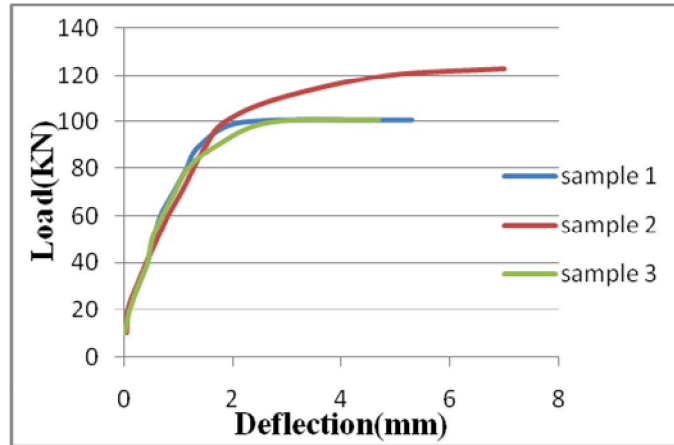


Fig. 3. Load deflection graph for OPC, PPC & PSC

The results of various tests conducted are summarized and shown in Table 1.

TABLE 1. TEST RESULTS FOR OPC, PPC & PSC

| TESTS | Types of Cement | | |
|---|---------------------|----------------------|---------------------|
| | OPC | PPC | PSC |
| Compressive strength of concrete cubes (N/mm ²) | 35 | 35 | 35 |
| Compressive strength of cylinder (N/mm ²) | 12.074 | 12.429 | 7.13 |
| Flexural strength on beam(N/mm ²) | 6.4 | 6.4 | 6.05 |
| Modulus of Elasticity(N/mm ²) | 2.8x10 ⁴ | 2.04x10 ⁴ | 1.5x10 ⁴ |
| Splitting tensile strength test(N/mm ²) | 4.22 | 3.818 | 3.819 |
| Strength test on reinforced beam KN m | 533 | 437 | 568 |

From the load deflection method, it is observed that the strength of PSC is greater than OPC and PPC. From the load deflection graph the energy absorbed by the beam in KNmm, is obtained by calculating the area from the graph. The initial cracking load is calculated by drawing a tangent from the initial point of the graph, which is the first point deviating from the graph. The results are shown in Table 2.

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TABLE 2 . ENERGY ABSORPTION OF REINFORCED BEAMS FOR DIFFERENT TYPE OF CEMENT (IMMERSED IN NORMAL WATER)

| Specimen no: | Energy absorption (kNmm) | | |
|--------------|--------------------------|-----|-----|
| | OPC | PPC | PSC |
| 1 | 438 | 261 | 540 |
| 2 | 726 | 432 | 591 |
| 3 | 435 | 618 | 573 |

D. CALOMEL ELECTRODE METHOD

According to this method if the potential of steel in concrete becomes more negative than -276mV vs SCE there is a 90% probability that corrosion will occur. However it is generally accepted that corrosion potential measurements must be complemented by other methods because although reliable relationships between potential and corrosion rate can be found on the laboratory for well established conditions these can in no way be generalized, since wide variations in the corrosion rate are possibly in very narrow range of potentials. Open circuit potential measurement is a useful technique in finding out the anodic and cathodic sites in reinforcing bars are exposed to the environments.

TABLE 3 . CORROSION RATE OBTAINED FROM CALOMEL ELECTRODE METHOD (IMMERSED IN NORMAL WATER)

| Specimen No | Voltage measured in mV | | |
|-------------|------------------------|------|-----|
| | OPC | PPC | PSC |
| 1 | -119 | -147 | -77 |
| 2 | -102 | -146 | -70 |
| 3 | -116 | -137 | -88 |

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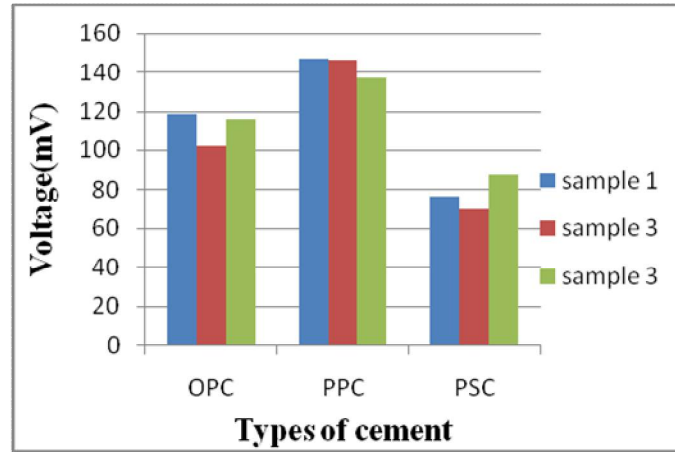


Fig. 4. Variation of Corrosion rate for various types of cement(immersed in normal water)

TABLE 4 CORROSION RATE OBTAINED FROM CALOMEL ELECTRODE METHOD (IMMERSED IN SALT WATER)

| Specimen No | Voltage measured in mV | | |
|-------------|------------------------|------|------|
| | OPC | PPC | PSC |
| 1 | -283 | -300 | -116 |
| 2 | -297 | -263 | -163 |
| 3 | -252 | -275 | -200 |
| 4 | -273 | -248 | -150 |
| 5 | -234 | -214 | -160 |
| 6 | -278 | -254 | -178 |
| 1 | -283 | -300 | -116 |

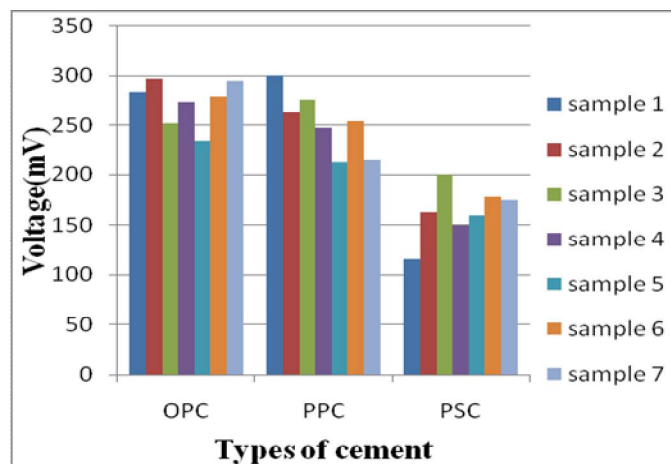


Fig. 5. Variation of Corrosion rate for different types of cement (immersed in salt water)

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E. Weight Loss Method

The cubes of size 75mm×150mm×150mm, that was prepared with OPC, PPC & PSC were used for weight loss method and loss in weight was calculated and shown in Table 5 and Table 6 and graphically represented in figure 6 and figure 7.

TABLE 5. CORROSION RATE MEASURED USING WEIGHT LOSS METHOD (IMMERSED IN NORMAL WATER)

| Specimen No | Corrosion measured in nm/hr | | |
|-------------|-----------------------------|------|------|
| | OPC | PPC | PSC |
| 1 | 2.30 | 9.70 | 0.98 |
| 2 | 3.95 | 9.56 | 0.94 |
| 3 | 3.62 | 8.20 | 0.99 |

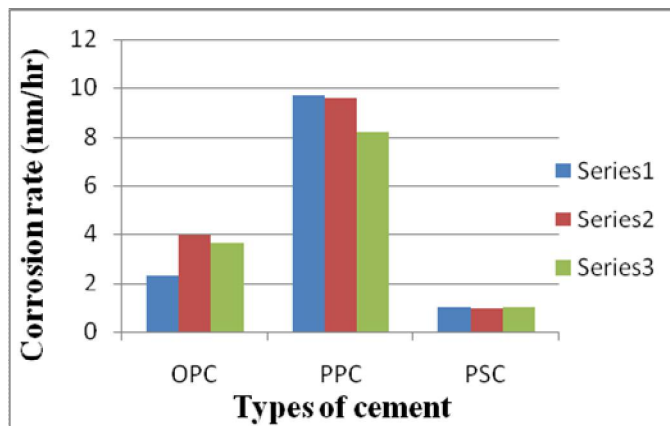


Fig. 6. Corrosion Rate measured using Weight Loss Method(Immersed in normal water)

TABLE 6. CORROSION RATE MEASURED USING WEIGHT LOSS METHOD (IMMERSED IN SALT WATER)

| Specimen No | Corrosion measured in nm/hr | | |
|-------------|-----------------------------|-------|------|
| | OPC | PPC | PSC |
| 1 | 8.56 | 11.09 | 1.64 |
| 2 | 5.99 | 10.65 | 1.64 |
| 3 | 6.21 | 10.21 | 1.58 |
| 4 | 6.96 | 10.08 | 1.51 |
| 5 | 6.31 | 10.64 | 1.24 |
| 6 | 7.23 | 11.09 | 1.97 |
| 7 | 6.56 | 11.56 | 1.97 |

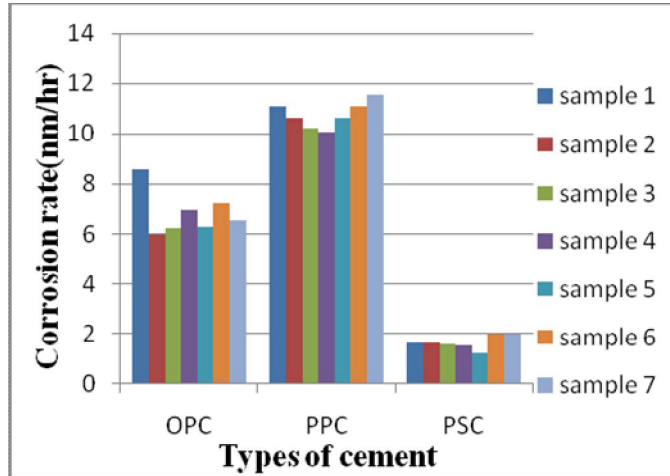


Fig. 7. Corrosion Rate measured using Weight Loss Method(Immersed in salt water)

F. TAFEL EXTRAPOLATION TECHNIQUE

The cubes of size 75mm×150mm×150mm, that was prepared with OPC, PPC & PSC were used for this method. The method was conducted in the Electrical lab and the anodic current, OCP, and voltage passing through the reinforcement was found out. The results are tabulated in Table 7 and Table 8 and graphically represented in Figure 8 and Figure 9.

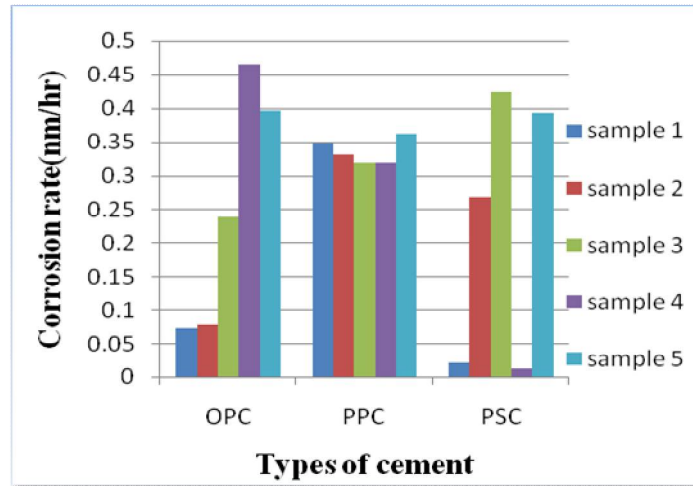


Fig. 8. Corrosion Rate measured using Tafel Extrapolation Technique of various type of cement (immersed in normal water)

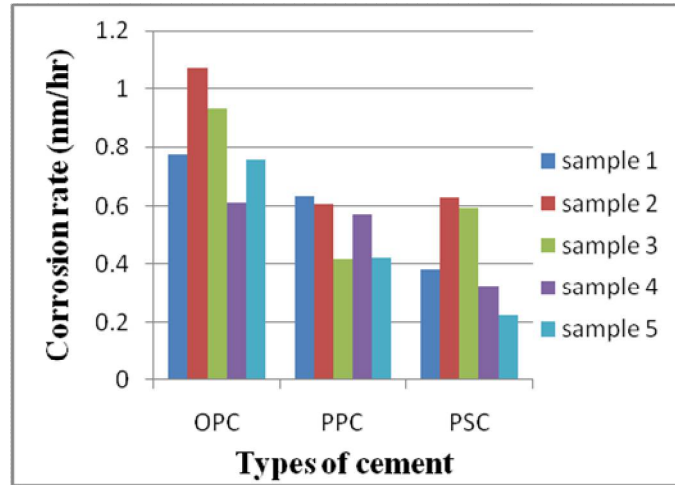


Fig. 9. Corrosion Rate measured using Tafel Extrapolation Technique of various type of cement (immersed in salt water)

TABLE 7. CORROSION RATE MEASURED USING TAFEL EXTRAPOLATION TECHNIQUE OF OPC (IMMERSED IN NORMAL WATER)

| Specimen number | OCP(V) | E_{corr} (mV) | I_{corr} mA/cm ² | C.R(mmpy) |
|-----------------|--------|-----------------|-------------------------------|-----------|
| 1 | -0.88 | -209 | 0.006 | 0.073 |
| 2 | -0.87 | -241 | 0.006 | 0.078 |
| 3 | -0.96 | -222 | 0.019 | 0.239 |
| 4 | -0.88 | -193 | 0.038 | 0.465 |
| 5 | -1.02 | -147 | 0.033 | 0.397 |

TABLE 8. CORROSION RATE MEASURED USING TAFEL EXTRAPOLATION TECHNIQUE OF PPC (IMMERSED IN NORMAL WATER)

| Specimen number | OCP(V) | E_{corr} (mV) | I_{corr} mA/cm ² | C.R(mmpy) |
|-----------------|--------|-----------------|-------------------------------|-----------|
| 1 | -0.98 | -174 | 0.029 | 0.348 |
| 2 | -0.96 | -208 | 0.027 | 0.331 |
| 3 | -0.98 | -181 | 0.025 | 0.319 |
| 4 | -0.97 | -209 | 0.026 | 0.318 |
| 5 | -0.96 | -197 | 0.030 | 0.361 |

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TABLE 9 CORROSION RATE MEASURED USING TAFEL EXTRAPOLATION TECHNIQUE OF PSC (IMMERSED IN NORMAL WATER)

| Specimen number | OCP(V) | E _{corr} (mV) | I _{corr} mA/cm ² | C.R(mmpy) |
|-----------------|--------|------------------------|--------------------------------------|-----------|
| 1 | -1.06 | -157 | 0.016 | 0.20 |
| 2 | -0.86 | -199 | 0.022 | 0.269 |
| 3 | -0.96 | -184 | 0.035 | 0.424 |
| 4 | -0.98 | -173 | 0.001 | 0.012 |
| 5 | -0.96 | -198 | 0.003 | 0.393 |

TABLE 10. CORROSION RATE MEASURED USING TAFEL EXTRAPOLATION TECHNIQUE OF OPC (IMMERSED IN SALT WATER)

| Specimen number | OCP(V) | E _{corr} (mV) | I _{corr} mA/cm ² | C.R(mmpy) |
|-----------------|--------|------------------------|--------------------------------------|-----------|
| 1 | -1.01 | -252 | 0.064 | 0.775 |
| 2 | -1.02 | -145 | 0.089 | 1.072 |
| 3 | -0.96 | -328 | 0.077 | 0.934 |
| 4 | -0.91 | -222 | 0.051 | 0.613 |

TABLE 11. CORROSION RATE MEASURED USING TAFEL EXTRAPOLATION TECHNIQUE OF PPC (IMMERSED IN SALT WATER)

| Specimen number | OCP(V) | E _{corr} (mV) | I _{corr} mA/cm ² | C.R(mmpy) |
|-----------------|--------|------------------------|--------------------------------------|-----------|
| 1 | -0.97 | -229 | 0.052 | 0.632 |
| 2 | -0.95 | -220 | 0.050 | 0.608 |
| 3 | -0.97 | -266 | 0.034 | 0.417 |
| 4 | -0.99 | -234 | 0.034 | 0.571 |
| 5 | -0.86 | -209 | 0.035 | 0.423 |

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TABLE 12. STANDARD VALUES OF CORROSION RATE ANALYSIS

| Relative corrosion | mmpy |
|--------------------|-----------|
| Outstanding | <0.02 |
| Excellent | 0.02-0.01 |
| Good | 0.1-0.5 |
| Fair | 0.5-1 |
| Poor | 1-5 |
| Unacceptable | 5+ |

From the test conducted it was found that the anodic current passing through the steel reinforcement is less for PSC. The corrosion rate obtained from the standard values for PSC is within the range.

VI. CONCLUSION

A study has been conducted on the effects of corrosion in blended cements that is by using PPC and PSC, by keeping OPC as the reference material.

1.It was observed from the corrosion study that the PSC has greater corrosion resistance when compared to PPC. The Tafel Extrapolation technique gave more accurate results when compared to Weight Loss and Calomel Electrode methods. The results can't be precisely inferred from the weight loss method due to shortage of time to extend the work for 60, 90 days.

2.It was found from the analysis that the compressive strength of cubes, flexural strength of beams, splitting tensile strength test of cylinders, compressive strength of cylinders and modulus of elasticity of cylinders when casted using PPC was found to be greater than that of PSC.

3.It was also found that with the use of blended cements, the slump value decreases there by giving higher workability to concrete mix.

4.In this study OPC was used as a reference material to carry out the project and the strength and corrosion results showed that it has poor performing characteristics when compared to the blended cements.

5. It was found that PPC can give better finishing to the surface and it is inferred that this cement can be effectively used for plastering, which adds the aesthetics.

6.Even though the compressive strength of cement is less than the specified IS value, the concrete mixes showed positive results. With better quality cement improved results could be attained.

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