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The Local Aggregates Performance's Test Against Severe **Environment on Different Quarry**

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Abstract. A concrete structure reinforced with reinforcing bars formed an important part on current infrastructures. The high compressive strength of concrete combined with a high tensile strength of steel give an ideal composite material which offer a wide range of application within civil engineering structures. The aim of this research is to observe the corrosion process on reinforcing bars of reinforced concrete structure which is made by local aggregates which have the compressive strength ranged from 25 to 30 MPa, with different quarry in the area of Special Region of Yogyakarta. The ASTM G-109 and Florida Test of Method FM 5-522 are chosen to conduct this research. The test was conducted 45 to 60 days with following data to be taken: water salinity (pH), voltage reading relative difference, reinforcing bar's mass loss. The data processed to obtain corrosion current density (CCD) and corrosion rate (CR). The results as follow : (1) the voltage difference's reading on each specimens attempt to be similar, (2) the CCD on each specimens behave differently with relative differences of 1,68%, (3) the CR on each specimens behave differently with relative differences of 0,66%, (3) the specimens behave similarly regardless the differences between two of them.

Keywords: corrosion rate, corrosion current density, local aggregates

1. Introduction

Reinforced concrete is a widely used construction material for bridges, buildings and platforms as well as for underground structures such as tunnels or reinforced concrete pipelines. In general, reinforced concrete is a very durable material capable of withstanding a large range of severe environments including marine, industrial and alpine conditions. Despite the fact that the majority of these structures show good long-term performance and high durability, there is still a large number of failures of concrete structures as a result of premature reinforcement corrosion.[1] Reinforcement corrosion is the main cause of damage and early failure of reinforced concrete structures worldwide with subsequent enormous costs for maintenance, restoration and replacement. [2] For example the European infrastructure has reached an age where the capital costs have decreased but the maintenance costs have grown to such an extent (5 billion EURO per year) that they constitute a major part of the current costs of the infrastructure. One estimate from the United States is that the cost of damage to reinforced concrete bridges and car parks due to de-icing salts alone is between 325 to 1000 million of EURO per year. In the UK, the Department of Transport estimates a total repair cost of 1 billion EURO due to corrosion damage on motorway bridges. These bridges represent about 10% of the total inventory in the UK.[3]

The problems not only faced by developed countries, but every country that develops reinforced concrete technology. The reinforced concrete will be very dependent on the availability of local

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aggregates where the concrete is made. This means that problems involving reinforced concrete will always be related to the availability of suitable local materials. Moreover, although in general the problems relating to corrosion in reinforced concrete structures in each country are the same, this is inseparable from the nature of the local materials used in the concrete mix, mixing, casting and curing treatment.

2. Reinforced concrete corrosion: process and mechanism

The conditions which lead to corrosion of steel in reinforced concrete structures are becoming well understood. Nevertheless, many existing concrete structures show significant corrosion, often when comparatively new, leading to the need for expensive repair. In most cases either the structures were not durable enough or the appropriate maintenance had been neglected. [1]

There are two main causes of corrosion of steel in concrete. The main causes are chloride attack and carbonation. These two mechanisms are unusual in that they do not attack the integrity of the concrete. Instead, aggressive chemical species pass through the pores and attack the steel. Other acids and aggressive ions such as sulphate destroy the integrity of the concrete before the steel is affected. Most forms of chemical attack are therefore concrete problems before they are corrosion problems. Carbon dioxide is very unusual in penetrating the concrete without significantly damaging it. Accounts of (for instance) acid rain causing corrosion of steel embedded in concrete are unsubstantiated as far as this author is aware. While the carbonation process affects the microstructure of the concrete it is not generally deleterious.[2]

There are four conditions that must be fulfilled to start and maintain the corrosion process, as follow:[1]

| | Condition for corrosion of steel in concrete | Condition is fulfilled, if: | |
|---|---|---|--|
| 1 | An anodic reaction is possible | The passive layer of the steel bar breaks down and depassivation of the steel occurs. This can be caused by carbonation of concrete and ingress of chloride into the concrete, reaching a critical level. | |
| 2 | A cathodic reaction is possible | Oxygen as the driving force of the corrosion process is available at the interface of the reinforcement in a reasonable amount. | |
| 3 | A flux of ions between the site of the anodic reaction and the site of the cathodic reaction is possible | The environment or electrolyte between the site of the anodic reaction and the site of the cathodic reaction conducts well. | |
| 4 | A flux of electrons is possible | There is a metallic connection between the sites of anodic and cathodic reactions. For monolithic reinforced concrete structures this condition is usually fulfilled. | |

Table 1. Conditions for corrosion of steel in concrete [1].

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Figure 1. Corrosion as an electrochemical process.[1]

2.1. Carbonation

Carbonation is the result of the interaction of carbon dioxide gas in the atmosphere with the alkaline hydroxides in the concrete. Like many other gases carbon dioxide dissolves in water to form an acid. Unlike most other acids the carbonic acid does not attack the cement paste, but just neutralizes the alkalies in the pore water, mainly forming calcium carbonate that lines the pores. [2]

Carbonation damage occurs most rapidly when there is little concrete cover of the reinforcing steel. It can also occur when the cover is high but the pore structure is open, pores are well connected together and allow rapid CO_2 ingress and when alkaline reserves in the pores are low. This occurs when there is a low cement content, high water cement ratio and poor curing of the concrete.

Many factors influence the ability of reinforced concrete to resist carbonation induced corrosion. As the carbonation rate is a function of thickness, good cover is essential to resist carbonation. As the process is one of neutralizing the alkalinity of the concrete, good reserves of alkali are needed, that is, a high cement content. The diffusion process is made easier if the concrete has an open pore structure. On the macroscopic scale this means that there should be good compaction. On a microscopic scale well cured concrete has small pores and lower connectivity of pores to the CO_2 has a harder job moving through the concrete. Microsilica and other additives can block pores or reduce pores sizes.[2]

2.2. Chloride attack

Chlorides can come from several sources. They can be cast into the concrete or they can diffuse in from the outside. Chlorides cast into concrete can be due to: (1) deliberate addition of chloride set accelerators (calcium chloride CaCl₂ was widely used until the mid-1970s), (2) use of seawater in the mix, (3) contaminated aggregates. Chlorides can diffuse into concrete due to: (1) sea salt spray and direct seawater wetting, (2) de-icing salts, (3) use of chemicals (structures used for salt storage, brine tanks, aquaria, etc.).[2]

Like carbonation, the rate of chloride ingress is often approximated to Fick's law of diffusion. There are further complications here. The initial mechanism appears to be suction, especially when the surface is dry, that is, capillary action. Salt water is rapidly absorbed by dry concrete. There is then some capillary movement of the salt laden water through the pores followed by 'true' diffusion. There are other opposing mechanisms that slow the chlorides down. These include chemical reaction to form chloroaluminates and absorption onto the pore surfaces.[2]

3. Impressed Current Method

The impressed current technique, also called the galvanostatic method, 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. 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 in

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corrosion can be calculated with the help of a gravimetric test conducted on the extracted bars after subjecting them to accelerated corrosion. Using the actual amount of steel lost in corrosion, an equivalent corrosion current density can be determined.[4]

Set-ups used for inducing reinforcement corrosion through impressed current consist of a DC power source, a counter electrode, and an electrolyte (Figure 3). The positive terminal of the DC power source is connected to the steel bars (anode) and the negative terminal is connected to the counter electrode (cathode). The current is impressed from counter electrode to the rebars through concrete with the help of the electrolyte (normally sodium chloride solution).

The mass of rust produced per unit surface area of the bar due to applied current over a given time can be determined theoretically using the following expression based on Faraday's law, as follow:

$$M_{th} = \frac{W.I_{app}.T}{F} \tag{1}$$

where M_{th} = theoretical mass of rust per unit surface area of the bar (g/cm²); W = equivalent weight of steel which is taken as the ratio of atomic weight of iron to the valency of iron (27.925 g); I_{app} = applied current density (Amp/cm²); T = duration of induced corrosion (sec); and F = Faraday's constant (96487 Amp-sec).

The actual mass of rust per unit surface area may be determined by gravimetric test in accordance with ASTM G1 [5] on rebars extracted from the concrete by breaking the specimens after the accelerated corrosion test is completed: (W = W)

$$M_{ac} = \frac{(W_i - W_f)}{\pi DL} \tag{2}$$

where M_{ac} = actual mass of rust per unit surface area of the bar (g/cm²); W_i = initial weight of the bar before corrosion (g); W_f = weight after corrosion (g) for a given duration of induced corrosion (T); D = diameter of the rebar (cm); and L = length of the rebar sample (cm).

The degree of induced corrosion is also expressed in terms of the percentage weight loss (ρ) calculated as:

$$\rho = \frac{W_i - W_f}{W_i} \times 100 \tag{3}$$

The equivalent corrosion current density (I_{corr}) can be determined by equating Equation 1 and Equation 2, assuming that the theoretical and actual mass of rust are equal (i.e., $I_{app} = I_{corr}$), as:

$$I_{corr} = \frac{(W_i - W_f)F}{\pi D L W T}$$
(4)

4. Methods

The research using fine aggregate from two different quarry. One quarry is a volcano deposit, and the other one is river deposit. Even though it is a volcano deposit, the quarry is on a stream-like river.



Figure 2. Accelerated corrosion test specimens and setup [4]

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The specimens were cast and moulded in a cylinder form with dimension of 10cm in diameter and 30cm in height. The rebar was placed in the middle of the cylinder. The form of cylinder caused the chloride solution will seep into the concrete from the side way of the specimens.[4] The test was setup according to FM 5-522 [6] with the total test duration of 90 days.

5. Result and Discussion

Accelerated corrosion testing illustrates the attack from a damaging environment (in this case the seawater / salt water environment of a certain consistency) on concrete structures that are moulded using materials from different quarries. During the test, periodically the potential changes of each specimen are read and recorded. In addition, changes in hardness of salted water solution are also noted. The results obtained in this study are data of potential difference, density of corrosion currents and corrosion rate of reinforcing steel.



Figure 3. Potential difference

The corrosion current density (I_{corr}) of each specimen made with a different quarry can be given as follows:

| spesimen | Quarry 1 | Quarry 2 | Relative differences | Relative differences percentage |
|----------|----------|----------|----------------------|---------------------------------------|
| 1 | 1,17E-05 | 9,71E-06 | 2,03E-06 | 17,29% |
| 2 | 1,46E-05 | 1,82E-05 | -3,6E-06 | -24,68% |
| 3 | 2,98E-05 | 2,7E-05 | 2,81E-06 | 9,45% |
| 4 | 8,48E-06 | 1,64E-05 | -7,9E-06 | -93,67% |
| 5 | 7,31E-06 | | 7,31E-06 | 100,00% |
| | | | Average | 1,68% |

| Table 2 | . C | orrosion | current | density |
|---------|-----|----------|---------|---------|
| | | | | 2 |

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Figure 4. Corrosion current density

The corrosion rate of specimens made with materials from different quarries can be given as follow:

| Table 3. Corrosion rate | | | | |
|-------------------------|----------|----------|----------------------|---------------------------------------|
| spesimen | Quarry 1 | Quarry 2 | Relative differences | Relative differences percentage |
| 1 | 1,17E-05 | 9,71E-06 | 2,03E-06 | 17,29% |
| 2 | 1,46E-05 | 1,82E-05 | -3,6E-06 | -24,68% |
| 3 | 2,98E-05 | 2,7E-05 | 2,81E-06 | 9,45% |
| 4 | 8,48E-06 | 1,64E-05 | -7,9E-06 | -93,67% |
| 5 | 7,31E-06 | | 7,31E-06 | 100,00% |
| | | | Average | 1,68% |



Figure 5. Corrosion rate

The specimens used in this study came from two different quarries, from mining at the Progo river and mining at Gendol river.

Referring to the graph of potential difference readings, specimens made using aggregates from the Progo river do not have different characteristics from specimens made with aggregates from Gendol river. Specimens made from the two quarries behave similarly. Potential readings of each specimen have

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a tendency of flat potential readings. This condition indicates that each specimen tested has good enough consistency, fluctuations in the reading are not too large. Thus, based on the results of the reading of potential differences, it can be concluded that there are no differences in characteristics between specimens made from aggregates from the Progo river and specimens made from Gendol river's aggregates.

Based on corrosion current density (CCD) data, it appears that each specimen has a different CCD value. This is influenced by the value of resistance given from the concrete and steel material itself, as well as the hardness of the solution. The same thing can also be seen from the corrosion rate (CR) value of each material tested. CR values obtained from each specimen also differ. Although the CCD and CR values are both influenced by the constituent material and the hardness of the solution, the two CCD and CR values are not positively correlated. This means that one specimen does not always have a harmonious relationship between the CCD and CR values. Looking at the behaviour of the specimens from the Progo river's quarry and the Gendol river's quarry, it appears that both have relatively uniform behaviour.

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