Effect of Salt-Contaminated Mixing Water and Aggregates on Time-to-Initiate Rebar Corrosion in Concrete

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Abstract— Durability problems occurring in reinforced concrete structures have become a major concern to end-users. Particularly, structures that are built near shoreline normally suffer premature deterioration due to corrosion of their reinforcing steel bars which is caused by continuous ingress of chlorides from seawater into the concrete cover. Making this problem more serious is the use of salt-contaminated mixing water and sea-based aggregates in making concrete – a very common practice in coastal rural areas where concrete ingredients are taken from near-shoreline sources. This study was conducted in order to quantify the effect of salt-contaminated aggregates and water on the time-to-initiate corrosion of steel bars in concrete. Six types of concretes was used: a control sample, concrete containing salty aggregates, concrete mixed on seawater, and concretes mixed with 10%, 20% and 30% salt solution, respectively. Corrosion monitoring was done via impressed current where the corrosion activity on steel bars was monitored by a Silver-Silver Chloride Electrode (SCE) under laboratory controlled conditions. Results have showed that concrete mixed with salt-contaminated aggregates and mixing water, produced a faster corrosion of steel bars than the normal concrete.

Index Terms— Durability, Deterioration, Corrosion, Time-to-Initiate Corrosion, Admixed Chlorides, Adsorption.

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1 INTRODUCTION

DETERIORATION of RC structures caused by rebar corrosion is a continuing and growing problem faced by the construction industry and the end-users [1]. According to Cabrera [2], this problem is very dominant along or near coastal areas where near-shoreline structures such as ports, bridges, resorts, and even residential and commercial buildings normally suffer premature, fast-paced, irreversible and uncontrollable type of deterioration due to continuous exposure to seawater which causes corrosion on their embedded rebars [2]. As a consequence, repeated and costly repair, maintenance, rehabilitation and even replacement works are undertaken on these structures in order to extend their service lives [3].

In the Philippines, this problem is manifested on the prohibitive cost of repair and maintenance works on marine structures incurred by both government and private sector [4,5]. What's more, deteriorating structures have to be maintained and repaired regularly, or even replaced several years before the expected end of their service lives as a result of premature deterioration [6]. But during the progress of repair and maintenance works, these structures are temporarily put off for use rendering interruptions in the flow of traffic which results to inconvenience on end-users [7] Besides, losses in revenue on the part of the government happens because the temporary closure of one structure will affect the operation of the other structures. For these reasons, the construction of

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hese sea-based structures should be based not just on sound and acceptable construction methods and practices, but also on the choice of quality materials specially those that are not harmful to concrete. Chloride ions, which is the primary source of corrosion of steel bars in concrete, enters into concrete either from external source or from internal source [8]. Externally, chlorides from the environment (such as seawater) penetrate into the concrete during its hardened state when the concrete structure is already in place, and internally, chlorides from the ingredients used in making concrete (such as salt-contaminated aggregates and water) is mixed into concrete at its fresh or fluid state. The later is the scope of this study.

2 MATERIALS AND METHODS

2.1 The Materials Used

The materials used in this study consist of cement, sand, gravel, and 12 mm diameter deformed steel bar. These materials were sourced out from local suppliers and manufacturers in City of Borongan. Cement used was ordinary Portland cement, Type 1, and in accordance to manufacturer's standard. Steel bar used was deformed steel bar, 12 mm diameter, also in accordance to manufacturer's standard. The aggregates used are made of mineral sand and gravel. To ensure a reliable result, only one type of each material was used in the whole experiment. The physical properties of aggregates (obtained through tests) are listed in Table 1.

2.2 Preparation of Materials

Immediately after the purchase, all materials were stored in a clean and dry place in the ESSU Engineering laboratory where the whole experiment was conducted. Prior to fabrication of

test specimens, sand was sieved in accordance to ASTM C33-

TABLE 1
PHYSICAL PROPERTIES OF AGGREGATES

Physical Properties	Sand	Gravel
Moisture Content, Air Dried (%)	31.46	6.07
Absorption (%)	38.54	4.07
Unit Weight, Tempered (kg/m³)	2125.00	2166.67
Unit Weight, Loose(kg/m³)	2000.00	2000.00
Bulk Specific Gravity, SSD	1.25	5.12

08 [9] and using the 0.3mm – 2.86 mm (#50 - #18) sieve, while gravel was graded using 12.0 mm – 19.5 mm (Size #6) sieve. The primary purpose is to obtain a uniform and consistent mix.

These aggregates were first washed with clean water to remove impurities (especially the initial chloride content) and then air-dried prior to their use. The physical properties of these aggregates were also tested, particularly on their moisture content, absorption, unit weight (ASTM C29-07) [10], and specific gravity (ASTM C127-07 & C128-07) [11,12].

In implementing this study, six types rectangular prism specimens measuring 100 mm x 100 mm x 200 mm specimens were used as described in Table 2. In order to obtain reliable results, six (6) replications for each specimen was used.

TABLE 2
CHARACTERIZATION OF THE SIX SPECIMEN

Spec. No.	Description
1	Normal Concrete
2	Concrete made using seawater
3	Specimen admixed with seawater
4	Specimen admixed with 10% NaCl solution
5	Specimen admixed with 20% NaCl solution
6	Specimen admixed with 30% NaCl solution

The concrete mix for each specimen was done in accordance to ACI 211.1-91R02 [13] which considers a weight basis for proportioning concrete ingredients. The computed amounts of the 4 ingredients (in kg/m3) for the 12 specimen are shown in Table 3.

In the preparation of specimens, the aggregates were first sieved, washed and air-dried and then weighed separately together with cement. Then all the ingredients were mixed, casted and initially cured for 24 hours. After removal from forms, the 14 days curing period using ponding method commenced. Reinforcing bars were fixed in place inside the squared molds before casting. Mixing procedure was adopted from ASTM C192-07 [14]. Immediately after the fresh concrete

was discharged from the mixer, its slump and unit weight was measured in accordance to the ASTM standards listed above. Sampling of specimens was done in accordance to ASTM C172-08 [14].

TABLE 3
THE AMOUNTS OF INGREDIENTS FOR EACH SPECIMEN

Sample	Water kg/m³	Cement kg/m³	Sand kg/m³	Pea-Gravel kg/m³
1	210	520	643	881
2	210	520	643	881
3	210	520	643	881
4	210	520	643	881
5	210	520	643	881
6	210	520	643	881

2.3 The Time-to-Initiate Corrosion Experiment

The time-to-initiate corrosion experiment was done in accordance to two international standards: The Impressed Current Method standardized by the State of Florida (FM 5-22) was used in the preparation of specimens and corrosion monitoring setup and the American Society of Testing Materials protocol (ASTM C876) [15,16] for the corrosion monitoring of steel bars. The overall experimental set-up is shown in Figure 1. As shown in Figure 1, the six (6) specimens were placed in a vessel containing seawater and each specimen were connected to a DC power supply adjusted to a volt reading of 6V. The electrical connections to each specimen is shown in Figure 2 where the positive terminal of the voltmeter was connected in series
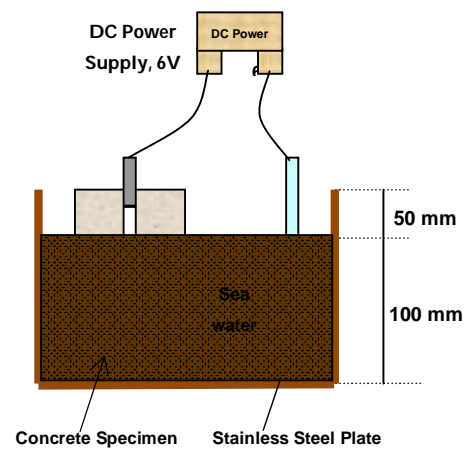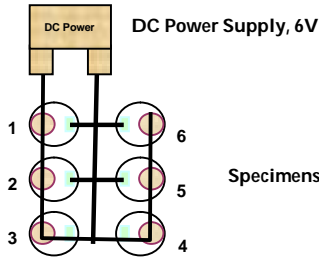

FIG.1. CORROSION EXPERIMENT SET-UP

FIG. 2. ELECTRICAL CONNECTIONS FOR IMPRESSED CURRENT

The corrosion activity of each specimen was monitored 2 times every day using a Silver Chloride Electrode (SCE) attached to a digital multimeter wherein the voltage reading was taken. Corrosion of steel bars commenced at a reading of -275 mV SCE. The procedure for reading is shown in Figure 3.
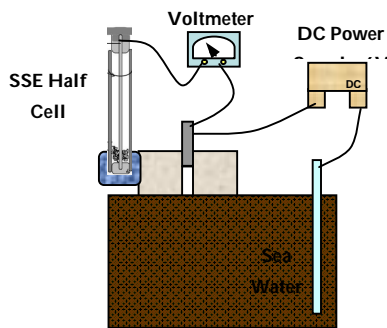

FIG. 3. CORROSION MONITORING SET-UP

3 RESULTS AND DISCUSSIONS

The corrosion monitoring data is shown in Figure 4 which shows the readings of the corrosion activity of each specimen against time. It can be observed from the Figure that, even on the first day of exposure, the six specimens have already different readings of corrosion activity which reflects initial corrosion stage on the specimen. Specimen 6 is already experiencing critical corrosion stage. This means that during the fourteen days curing period the chloride ions which were admixed to concrete have already reach the surface of the steel bars and its depassivation has already taken place. As basis of Silver Chloride Electrode (SCE) readings, the more negative its value the more advanced its corrosion stage is. Likewise, Figure 4 shows that as more amount of chlorides is mixed with concrete, the shorter its corrosion period of its rebars. This is further emphasized further in Figure 5.

The most important information that was found out in this study is that using salty water and salt-contaminated aggregates in making concrete have almost similar effect in terms of corrosion of steel bars in concrete (Figure 5). Assuming all other parameters affecting corrosion (e.g., penetration of external chlorides and environmental conditions) being constant this will mean that the service life of the structure will be reduced by over 38% if one will use salty water or aggregates, compared to normal concrete. For instance, if an owner wishes his or her building to last 50 years without repairs, a ne-

glectful contractor will reduce its serviceable life span to merely 30 years after using an unwashed sea-based aggregates or salt-contaminated water in its construction.
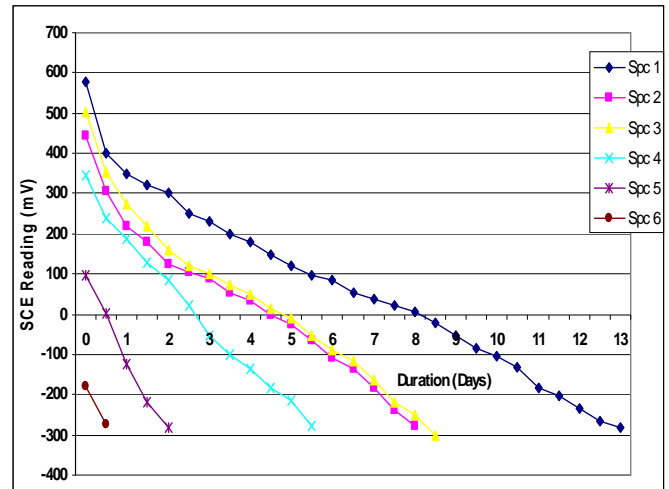

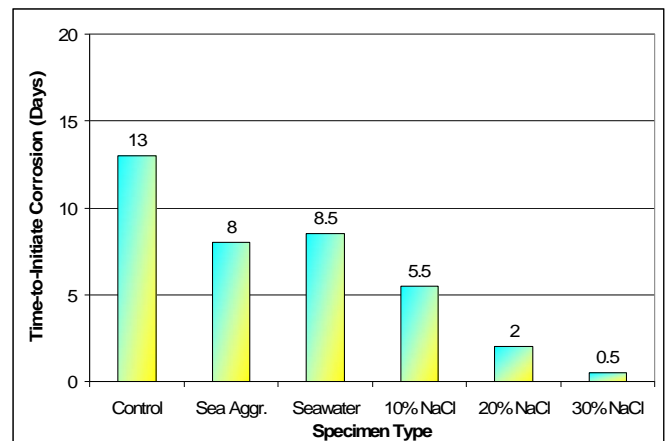FIG. 4. DAILY CORROSION MONITORING RESULT ON SIX SPECIMENS

FIG. 5. TIME-TO-INITAITE CORROSION ON SIX SPECIMENS

4 CONCLUSIONS

Due to the alarming problem on deterioration of reinforced concrete structures caused reinforcement corrosion which happens to be a socio-economic concern to both the government and the private sector this study was conducted in order to educate owners and builders on the effect of using salt-contaminated water and aggregates in making concrete.

To carry out the objectives of this study, an experimental study was conducted using a scientific and internationally accepted testing protocol. Based on the result, using salt-contaminated water and aggregates in making concrete will shorten the time-to-initiate corrosion of its embedded rebars, in fact, the more amount of chlorides is used, the shorter the corrosion period of rebar in concrete is. Also, it was quantitatively determined that the effect of using seawater and salty

aggregates in making concrete have almost similar effect when it comes to the pace of corrosion activity of embedded steel bars. In general, it was learned from this study that internally mixed chloride is very detrimental to concrete structures because the same will shorten their service lives through immediate corrosion of their rebars. Thus, using salt-contaminated ingredients – by all means – should not be permitted in making concrete.

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