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Determination of Corrosion Mass Level of Reinforced Concrete with and without Polypropylene Fibers using the Mass-Loss Measurement Method

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Abstract:

The service life of the structure is an important aspect of the design process. It is necessary to have a fundamental understanding of the factors that affect the structure's service life. In reinforced concrete structures, the parameters that determine the structure's service life may be governed by the rate of structural deterioration. The deterioration rate could be related to the agents from the environment surrounding the concrete structure. This paper covers the fundamentals of steel reinforcement corrosion in concrete with an emphasis on chloride-induced corrosion. The possible improvement of the mechanical property of concrete mix is through adding fiber material. The experimental work involves the fabrication of three (3) samples each for the concrete mixed with polypropylene 0.00%, 0.50%, 1.00%, 1.50%, and 2.00% with 14-day compressive strength concrete mixes were analyzed. The specimen having 150 mm width, 150 mm depth, and 500 mm length is reinforced with a 12 mm ribbed type bar. Subsequently, the casting and curing of beams were subjected to accelerated corrosion by using the impressed current method with 3 days of wetting and 4 days of drying processes. A plot between applied current density and time taken for the 8 weeks of accelerated corrosion by using the impressed current method. Theoretical mass loss as a result of corrosion is evaluated using Faraday's law.

Keywords **—Accelerated Corrosion, Corrosion Penetration Rate, Fiber Reinforced Concrete, Polypropylene fiber.**

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I. INTRODUCTION

Concrete provides natural corrosion protection to the embedded steel with its inner alkaline environment pH (12 to 13), the concrete pore water solution results in the formation and maintenance of a passive film or oxide layer on the surface of the reinforcing steel [1]. As long as the oxide layer on the reinforcing steel remains intact, the rate of corrosion is very low. However, if the oxide layer is broken, oxygen will be able to react with the steel, resulting in corrosion [2]. The exposure of the structure in the coastal area increases its susceptibility to the corrosion of the reinforcing steel may gradually deteriorate the concrete during its service life.

Chloride ions are a big contributor to corrosion in concrete, they weaken the passivity of the reinforcement and increase the active corrosion rate of steel. Corrosion does not occur for steel in concrete that is either dry or continuously saturated because both air and water are required for corrosion to be initiated. Steel will remain corrosion-resistant in concrete if the concrete cover prevents air and water from reaching the embedded reinforcement.

The possible improvement of the mechanical properties of concrete mix is through adding fibers e.g., steel fiber, glass fiber, synthetic fibers, and natural fiber materials. Synthetic fiber, such as polypropylene fiber is characterized by low specific gravity, low cost, prevents spalling in case of fire, and is non-corrosive in nature. This type of fiber is durable with long service life. However, it cannot be assumed by increasing the amount of fiber will continuously improve the mechanical properties of the reinforced concrete with fiber compare to the reinforced concrete without fiber. Consequently, the percentage amount per volume of concrete mixture will be studied.

The corrosion process can be artificially accelerated by increasing the chloride ion concentration in the concrete. Thus, breaking the passive layer and allowing the rate of corrosion to increase exponentially [3]. Induced corrosion on concrete and mortar beam specimens with a centrally placed steel bar by immersing the specimens in a 5% NaCl solution and connecting the positive terminal of a Direct Current (DC) power supply to the exposed steel bar as well as the negative terminal to stainless steel plates placed near the specimens in the solution. The corrosion process was initiated by applying a constant 30 V anodic potential. It was reported that the current going to the concrete and mortar specimens increased suddenly whenever the specimen cracked [4]. The time that takes for the reinforced concrete specimens to achieve a specific degree of corrosion or the percentage mass loss of the cross-sectional area of the rebar using the impressed current method, varies with the properties of the mix design, including pH, porosity, fine content, water/cement ratio, among others [5].

II. OBJECTIVES

The study focused on evaluating the significant effect of Polypropylene fiber mixed with concrete with of 0.00%, 0.50%, 1.00%, 1.50%, and 2.00% on mechanical properties of reinforced concrete, including the reduction of the corrosion in reinforcing bar after being subjected to accelerated corrosion for 8 weeks.

III. METHODOLOGY

A. Materials

The experimental design of concrete mixture involves 0.00%, 0.50%, 1.00%, 1.50%, and 2.00% proportions of Polypropylene fiber. The addition of fibers can improve the ductility of concrete prevent or reduce cracking and maintain the bond of reinforcing bar and concrete [6].

Polypropylene Fiber: the addition of polypropylene fibers is mainly focused on crack resistance, mechanical properties, and permeability [7].

TABLE I
PHYSICAL AND MECHANICAL PROPERTIES OF POLYPROPYLENE FIBERS.

Polypropylene Fibers

Length	54mm
Tensile Strength	400Mpa
Elastic Modulus	4.0Gpa
Density	0.91g/cu.m
Melting Point	160°C

FIG. II
APPEARANCE OF THE POLYPROPYLENE FIBERS

Water/Cement Ratio: the water/cement ratio used was 0.45 specified by the Structural building code (ACI 318-11) was used for the design of a reinforced concrete structure located in the coastal environment.

Reinforcing Steel: High-yield 12 mm diameter steel reinforcement bars (ribbed) were used for all the beam specimens. It is the most common type of reinforcing steel used in practice and is therefore preferable for investigating corrosion.

Chloride Solution: A 3.5% NaCl solution was used to simulate the coastal environment. Potable water was used in the preparation of the solution. The proportion mixed was 60 L of water with 2.1kg of NaCl. This procedure simulates the amount of Sodium chloride in coastal areas.

B. Casting and Curing

The beam specimen has 150 mm width, 150 mm depth, and 500 mm length for plain concrete and polypropylene fiber mixed concrete with 3000 psi concrete strength. To reduce the corrosion of the embedded steel due to the ingress of chlorides from an external source, it is essential to ensure adequate concrete cover for reinforcement. The National structural code of the Philippines 2015 recommends a minimum concrete cover of 40mm (Table 428.4.1). The curing of a specimen requires 14 curing days.

TABLE IIII
CONCRETE DESIGN MIXTURE

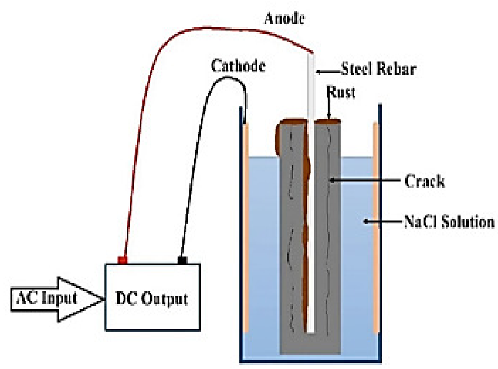
Material	*Batch 1*	*Batch 2*	*Batch 3*	*Batch 4*	*Batch 5*
	0.00%	0.50%	1.00%	1.50%	2.00%
Cement	9.9	9.9	9.9	9.9	9.9
Fine Aggregate	19.27	19.31	19.20	19.20	19.23
Coarse Aggregate	23.48	23.48	23.48	23.47	23.48
Polypropylene	0	0.020	0.040	0.060	0.080

Table 2 shows the design mixture in kilograms per batch. During the preparation, the materials were weighed using the concrete ratio of M20 with a mix ratio of 1:1.5:3. The aggregates used were partially dry; as a result of time constraints, and the absence of an oven to cater to the aggregates used for the preparation of the samples.

C. Accelerated Corrosion by Using Impressed Current Method

For the preparation specimen were kept first in an air-dried condition for 14 days, then they undergo cyclic wetting and drying for continuous movement of moisture through the specimen. cycle for 8 weeks and the weighing of samples was monitored weekly.

FIG. IVI
M. DIXIT (2021), IMPRESSED CURRENT TECHNIQUE SETUP



The corrosion of steel in reinforced concrete structures requires a long-term process. The Impressed current method is used for inducing corrosion in a shorter period. The corrosion was induced through an impressed current using an electric power supply (9 volts adapter was used), and the corrosion penetration rate was experimentally investigated using faraday's law.

The 15 concrete samples (150mm x 150mm x 500mm) with 12mm reinforcing bars were monitored weekly and undergo with 3 days of wetting or partially submerged in 3.5% NaCl solution with impressed current and 4 days of drying cycle.

D. Testing and Evaluation

ASTM standard C143: The standard test method for slump of hydraulic-cement concrete. the freshly mixed concrete is placed in a mold and compacted by a rod, as the mold is raised and the concrete will subside, the displacement of the concrete mixture is measured and reported as the slump of the concrete.

The slump is a measure of the consistency of the sample concrete mix, the test used for the determination of workability and densities for both plain concrete and fiber mixed concrete. the appropriate value of slump can be selected from table 3.

TABLE VII
RECOMMENDED SLUMP FOR VARIOUS TYPES OF CONSTRUCTION (ACI211.1-91, TABLE 6.3.1)

Types of Construction	*Slump, mm*	
	Maximum	*Minimum*
Reinforced foundation walls and footings	75	25
Beams	100	25
Columns	100	25
Pavement and slabs	75	25
Mass concrete	50	25

ASTM standard C78: The third-point load test in accordance with ASTM C78 evaluates the flexural strength of the concrete sample before it yields. The result was reported as modulus of rupture (MOR). The strength of the specimen is dependent on preparation, size, moisture content, and curing time.

FIG. VIII
STANDARD TEST METHOD FOR FLEXURAL STRENGTH OF CONCRETE

Corrosion Penetration Rate (CPR): The method used to measure corrosion rate was the mass loss method or the measurement of the Corrosion Penetration Rate (CPR) which is expressed in mile/s per year (mpy) or millimeter per year

(mmpy). The thickness loss of material per unit of time or Corrosion Penetration rate can be determined by the expression below;

$$CPR=KW/\rho At \quad (1)$$

Where:

K is a constant depending on the units used; when K is 534 then mile per year will be used, when K is 87.6, then mm per year.

W total weight loss (expressed in mg) after the exposure time.

ρ density (g/cm^3) of material.

A total surface area (cm^2) of material submerged.

t total exposure time of material submerge expressed in hours.

IV. RESULTS AND DISCUSSIONS

ASTM standard C143: The concrete slump test is to determine the workability or consistency of the concrete mix. A concrete slump test is carried out from batch to batch to check the uniform quality of concrete per mixture of the sample. It is used to determine the correct hydration of a batch of concrete samples[9].

TABLE VIIV
SLUMP TEST

Fiber	*Water (L)*	*Slump, (mm)*
0.00%	4.5	75.20
0.50%	4.5	70.50
1.00%	4.5	67.50
1.50%	4.5	58.20
2.00%	4.5	50.80

The workability and flow characteristics of the concrete mixture,are reduced with the addition of polypropylene fibers in the mix; however, segregation and bleeding of the concrete mixture are reduced as shown in Table 4.

Corrosion Penetration rate: Table 5 shows the average weight of three (3) samples per batch of 0.000%, 0.50%, 1.00%, 1.25%, and 2.00% of week 1 and week 8.

TABLE V
WEIGHT OF CONCRETE SAMPLE IN KG

Week	*Week 1*	*Week 8*
0.00%	28.315	27.687
0.50%	26.833	26.456
1.00%	27.801	27.585
1.50%	27.881	27.681
2.00%	27.505	27.362

(1)

Where:

K k is mm per year, then 87.6.

W total weight loss (expressed in mg) after the exposure time, see table 4.

density of steel 7.85 g/cm^3

T total surface area of submerge material 24.504 cm^2.

t total exposure time of material submerge expressed in hours, 1344 hrs.

FIG. VIIIV
8-WEEK CORROSION PENETRATION RATE

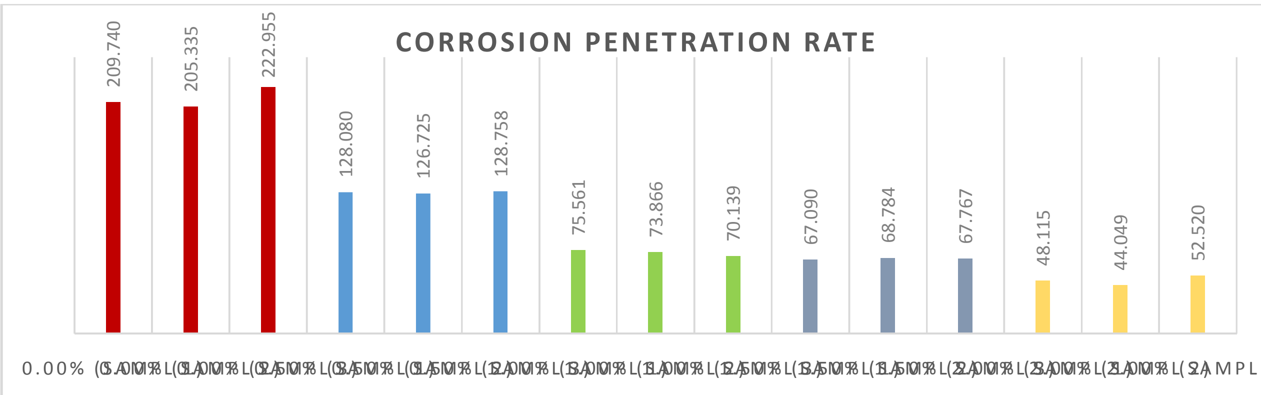
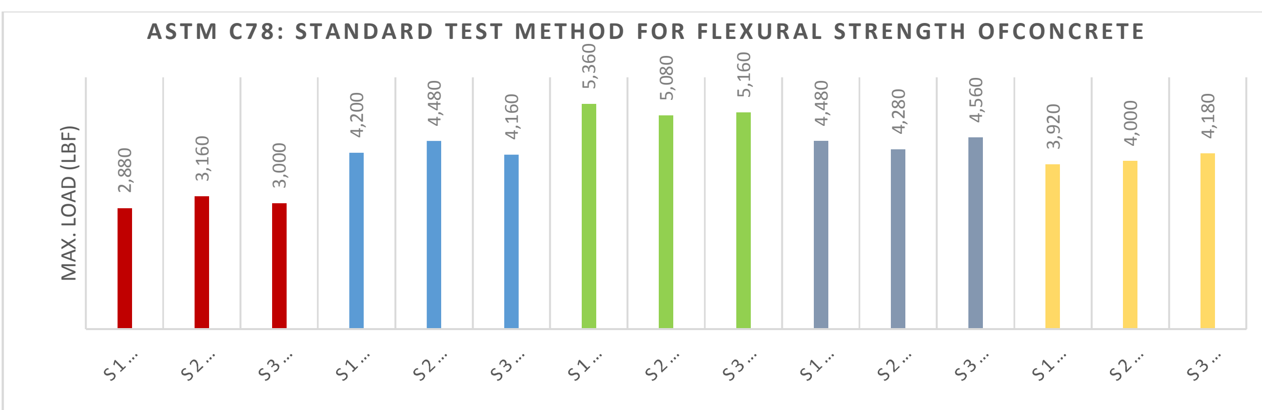


Figure 4 shows the summary of the corrosion penetration rate (CPR) of the three (3) samples per fiber percentage. As can be seen in the figure, most samples in concrete fiber mixed with 0.00%, experienced the most corrosion-induced and mass loss of the reinforcing bar. This might be due to the higher porosity of the concrete that permitted the corrosion to develop faster than the fiber-mixed reinforced concrete. Moreover, the figure expresses an inverse linear observation; as the fiber percentage increases the corrosion penetration rate decreases.

ASTM standard C78: This test method determines the flexural strength of concrete by the use of a simple beam with third-point loading. The result is reported as the modulus of rupture, where the flexural strength of the concrete sample prior to its yielding point.

FIG. V
ASTM C78 (14-DAY OLD CONCRETE BEAMS UNDERGO ACCELERATED CORROSION)



In figure 5, the concrete samples were subjected to an accelerated corrosion method after 14 days of curing method. The concrete mixed with polypropylene fiber seems to have a beneficial effect on the flexural strength of the material. The concrete mixed with 1.00% of polypropylene fiber has the highest flexural strength; showing a 33.33% increase in the plain concrete flexural strength.

Analysis of Variance (ANOVA): F-test is a statistical test in which the test statistic has an F-distribution under the null hypothesis. The result shows in the table 5 the rejection of the null hypothesis. Thus, there is a significant difference between the samples with and without polypropylene fiber.

TABLE V
RESULT OF F-TEST

Variance	*Between*	*Within*
Sum of square	13,337,333.33	426,667
DF	4	10
MSS	13,337,333.33	426,667
F	78.148	
Significant level	0.05	
F critical	3.48	
Decision	Reject HO	
Interpretation	Significant	

V. CONCLUSIONS

For the same water-cement ratio used, the addition of polypropylene fiber into concrete samples creates low workable or low flow characteristics of the concrete sample; however, the measured slump is within the recommended slump for ACI211.1-91 (table 6.3.1). Thus, as the percentage of the fiber increases the workability of the concrete decreases.

Polypropylene fiber reinforced concrete has been found to have a higher corrosion resistance than normal reinforced concrete. As observed as the fiber percentage increases, the corrosion penetration rate decreases. This might be due to the higher porosity of the concrete that permitted the corrosion to develop faster than the fiber-mixed concrete.

Polypropylene is beneficial to the concrete reinforced mixture. As compared to the flexural strength of the samples, it was observed that 0.00% polypropylene mixed fiber had the lowest flexural strength. The strength of the reinforced concrete mixed with polypropylene fiber is increasing up to 1%. After 1% the strength was reduced; showing a 33.33% increase in the plain concrete flexural strength.

For the analysis of variance, the result shows the rejection of the null hypothesis. Thus, there is a significant difference between the flexural strength of the samples with and without polypropylene fiber.

Causal Productions wishes to acknowledge Michael Shell

RECOMMNEDATIONS

The concrete design mixed with 1.00% of polypropylene fiber is recommended to be used in a structure near an environment rich in chloride. Moreover, for the improvement of concrete durability by using polypropylene fiber, future research may consider the physical characteristics of the fiber; the micro and macro polypropylene fibers.

It is also recommended to maximize the curing days up to 28 days to ensure the sample meets the standard. In addition, and prior to the casting of the concrete mixture, the aggregate's sample must be oven dry first. For the enhancement of the concrete mixture, composite fiber on the concrete mixture should be further studied.

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