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Comparison of Chloride Penetration Depth in Type I and Type IP Cement Concrete

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Abstract

Chloride ions that penetrate concrete and reach the embedded steel bars instigate the process of corrosion. This study investigated the chloride resistance of concrete by comparing the chloride penetration depths in Type I and Type IP cement concrete specimens. The water-to-cement ratios used were 0.55 and 0.65, while the curing periods were set at 7 and 28 days. After curing, the specimens were exposed to laboratory-simulated submerged and tidal conditions. The depths of chloride penetration in the specimens were then determined using colorimetric tests. The results showed that Type IP cement concrete exhibited significantly lower chloride penetration depths ($P < 0.05$) as compared to the Type I counterpart. Lower chloride penetration depths were seen in specimens with lower water-to-cement ratio of 0.55 and longer curing period of 28 days. Furthermore, significantly higher chloride penetration depths occurred in specimens exposed to submerged condition compared to those exposed in tidal condition.

Keywords: chloride penetration of concrete, concrete in marine environment, assessment of concrete performance, chloride ions and steel corrosion

Introduction

Corrosion of reinforcement in concrete can initiate when chloride ion concentration in contact with steel bars exceeds a threshold value (Masi, Colella, Radaelli & Bertolini, 2007). The chloride ions destroy the passive layer of the steel surface, allowing air and moisture to freely react with the steel bar and igniting a corrosion process. As rate of corrosion increases, it causes spalling of the concrete cover. This results in the sufficient reduction of the bar cross section, rendering the structure incapable of safely supporting its design loads (Richardson, 2002).

In the Philippines, the major source of chloride ions to penetrate concrete structures is seawater. The country, being an archipelago, has 36,289 km of vast coastlines. It is in these coastal areas that the industrial sector strategically situates its infrastructure and where urban development plans are geared.

Despite the increasing number of structures being subjected to deleterious actions of chloride, the issue is not yet fully addressed by authorities. For concrete practice in the country, corrosion of concrete reinforcement or concrete durability in general is not given as much attention as concrete strength. For quality control purposes, samples of structural members are tested with regards to their strength (i.e., compressive strength, flexural strength, stiffness). However, there is no established test for concrete durability. Though strength potential of concrete is reached, its potential for durability and weather acceptability is not always achieved in practice. The reason for this is the failure to recognize that different concretes and their components have different potentials, and some environment both inside and out of concrete are extremely aggressive.

A recent development in the Philippines is the increasing use of Type IP cement, a blend of Portland-pozzolan, as an alternative for Type I cement. This owes to the abundance of natural pozzolans in the country in the form of volcanic ash (Kirk & Zulueta, 2000). Type IP is being used as general purpose cement and is documented to exhibit greater strength after 28 days of curing compared to normal Portland cement concrete (Derucher, 1988). However, little is known about the durability potential of locally produced Type IP compared to Type I cement.

Thus, in this study, the performance of Type I and Type IP cement concrete was investigated by determining and comparing their durability in a marine environment. Concrete specimens made of Type I and Type IP cement were exposed to laboratory simulated marine environment conditions (submerged and tidal conditions). Variations on the specimens' water-to-cement ratio and curing period were considered. The chloride penetration depths and chloride concentration on the concrete were determined in order to compare the performance of Type I and IP cement concrete against chloride attack.

Materials and Methods

The main materials are the Type I and Type IP cements that were purchased from a local hardware store. The chemical compositions of the cements are shown in Table 1. River sand was used as fine aggregates while crushed rocks were used as coarse aggregates. The physical properties of fine and coarse aggregates are shown in Table 2. The cylindrical concrete specimens were prepared in the laboratory using the mix proportion summarized in Table 3. The concrete specimens were designed, mixed casted as cylinders and cured following the standard practices for making concrete specimens in the laboratory (ASTM C192). The concrete specimens were cast on 150mm x 300mm cylinder molds. The water to cement ratio considered were 0.55 and 0.65. The curing periods were set at 7 and 28 days.

Table 1. Chemical composition of Types I and IP cement (%)

Cement	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
Type I	21.80	5.10	3.00	63.80	1.70	2.00
Type IP	21.45	6.00	3.50	65.00	1.18	3.56

Table 2. Physical properties of fine and coarse aggregates

Kind of aggregate	Specific gravity in SSD	Fineness Modulus
Fine Aggregate	2.80	3.00
Coarse Aggregate	2.50	7.00

Table 3. Mix proportions of concrete specimens

w/c	Type of cement	Water	Cement	Sand	Gravel
		(kg/m^3 of concrete)			
0.55	I	187	339	884	926
	IP	187	339	875	918
0.65	I	190	292	938	908
	IP	190	292	931	900

Over a period of 60 days, the specimens were exposed in laboratory simulated submerged and tidal (wet-dry) conditions. The specimens were completely submerged in 3% NaCl solutions to simulate the condition of the sea. Another set of specimens were also exposed to cycles of wet and dry conditions. The specimens were submerged for 12 hours then removed from submersion, followed by exposing them to the atmosphere for another 12 hours. In order to minimize the changes in the salinity of the solution, the 3%

solution was removed and replenished every 7 days.

After the exposure period of 60 days, colorimetric test was performed. The cylindrical specimens were rinsed with distilled water and then fractured or split cylindrically. The fractured surfaces were sprayed with 0.1 M silver nitrate solution. After about 15 minutes, the chloride penetration depths were measured on several points at the middle-third portion where the silver chloride precipitation was visible on the fractured surface area (Figure 1) using a digital calliper. These portions were selected as test points based on previous studies about measurements of water permeability in concrete specimens by Ludirdja et al. (1989).

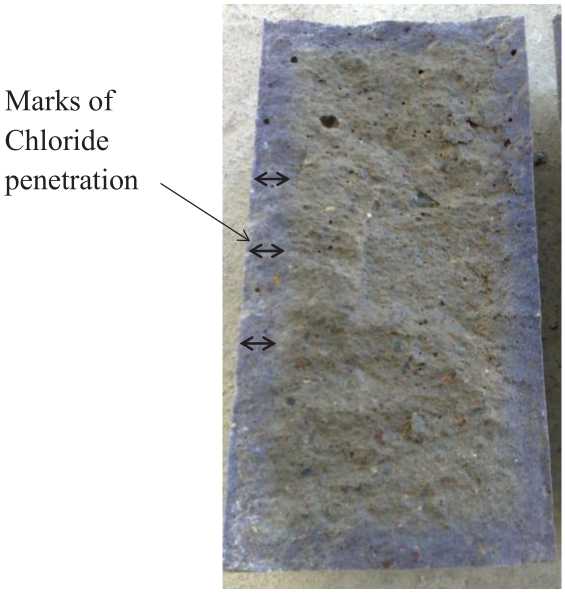

Figure 1. Determination of the chloride penetration depth.

Results and Discussion

The concrete specimens that were prepared using Type IP cement and exposed under submerged condition have lower chloride penetration depths as compared to Type I. Similar results were observed using Type IP cement exposed under tidal conditions. The lowest chloride penetration depth was observed for Type IP cement concrete specimens with lower water-to-cement ratio of 0.55 and longer curing period of 28 days, for both exposure conditions (Table 4).

Table 4. Average chloride penetration depths in concrete specimens

Type of cement	Water-cement ratio	Curing period (days)	Exposure condition	Average chloride penetration depth (mm)
I	0.55	7	submerged	25.36
IP	0.55	7	submerged	25.00
I	0.65	7	submerged	30.67
IP	0.65	7	submerged	29.81
I	0.55	28	submerged	24.37
IP	0.55	28	submerged	22.87
I	0.65	28	submerged	27.64
IP	0.65	28	submerged	26.88
I	0.55	28	tidal	20.63
IP	0.55	28	tidal	18.89
I	0.65	28	tidal	21.74
IP	0.65	28	tidal	21.39

The better performance of concrete specimens with Type IP cement in terms of chloride penetration maybe attributed to its pozzolanic reaction, as discussed by Mehta (1986). Type IP cement contains fly ash, which reacts with calcium hydroxide released during cement hydration to form additional calcium-silicate-hydrates. This product is a more stable and impermeable substance that fills the existing capillary spaces. Thus, its formation may have significantly contributed to the specimens' resistance against chloride ion penetration. The pozzolanic reaction also contributed towards the formation of better interfacial transition zones (ITZ), which was manifested only after a longer curing period (Mehta, 1986). This explanation can be better seen if there were visual evidences such as SEM images of the ITZ's.

The average chloride penetration depths in concrete specimens were computed and are shown in Table 4. Based on the table, the concrete specimens that were prepared using Type IP cement and exposed under submerged condition have lower chloride penetration depths as compared to Type I. Similar results were observed for concrete specimens that were prepared using Type IP cement and exposed under tidal condition. The lowest chloride penetration depth is observed for Type IP cement concrete specimens with lower water-to-cement ratio of 0.55 and longer curing period of 28 days, for both exposure conditions.

In terms of water-cement ratio, Figures 2 and 3 show that as the water to cement ratio of both Type I and Type IP concrete specimens increased, the depth of chloride penetration for the submerged samples also increased.

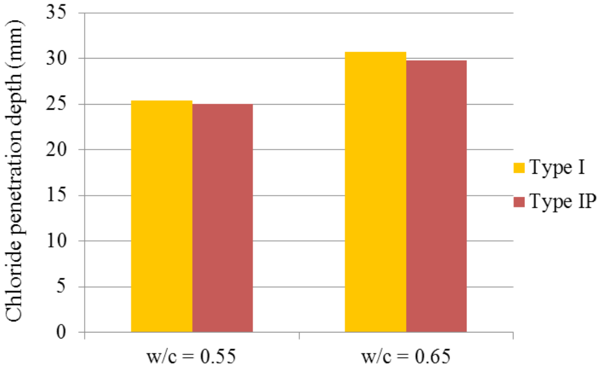

Figure 2. Chloride penetration depths of concrete cured for 7 days

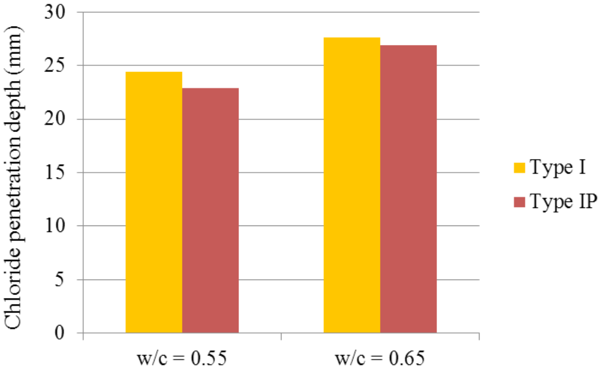

Figure 3. Chloride penetration depths of concrete cured for 28 days

To determine the significance of the effects of the factors considered, analysis of variance using F-test showed that only the main effects of type of cement, water-cement ratio, curing period, and exposure conditions are significant (p-value= 0.0269, 0.0001, 0.0001, 0.0001 < 0.05.) as shown in Table 5.

Further statistical test using pairwise mean comparison using least significant difference test was done to test the significance of the difference in the effects of each factor. Result of the analysis implies that all the levels chosen for each factor are significantly different in terms of affecting the chloride penetration as shown in Table 6.

Table 5. Analysis of variance of the chloride penetration

Source of variation	DF	Type III SS	Mean Square	F Value	Pr >F
Type	1	67.8972	67.8972	4.95	0.0269
wc	1	1363.8546	1363.8546	99.39	<0.0001
Curing	1	397.0556	397.0556	28.93	<0.0001
Exposure	1	1389.8057	1389.8057	101.28	<0.0001
Type*wc	1	3.7780	3.7780	0.28	0.6002
Type*curing	1	0.6453	0.6453	0.05	0.8285
Wc*curing	1	30.2815	30.2815	2.21	0.1385
Type*wc*curing	1	3.6326	3.6326	0.26	0.6073

Table 6. Pairwise mean comparison test results among the significant factors

Significant factors	Average chloride penetration*
Type of cement	
I	25.6652a
IP	24.7575b
Water-Cement Ratio (wc)	
0.65	27.0926a
0.55	23.3301b
Curing	
7 days	25.8749a
28 days	24.5478b
Exposure condition	
Submerged	26.5758a
tidal	20.6632b

*Using least Significant Difference Test, means with the same letter are not significantly different at α = 5%

Comparison of the results of chloride penetration depths in concrete specimens exposed to submerged and tidal conditions are shown in Figures 4 and 5. From the results, it can be seen that significantly higher chloride penetration depths occurred in concrete specimens exposed to submerged condition. Similarly, this observation in concrete specimens can be explained by the fact that moisture was continuously present in the submerged condition and therefore water continuously penetrated through the pores carrying with it the chloride ions.

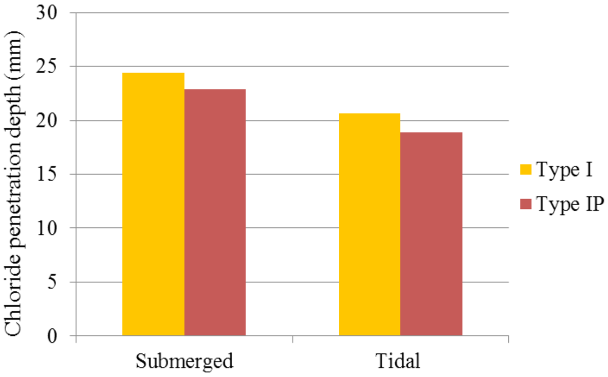

Figure 4. Chloride penetration depths in concrete specimens (w/c=0.55) exposed to submerged and tidal conditions

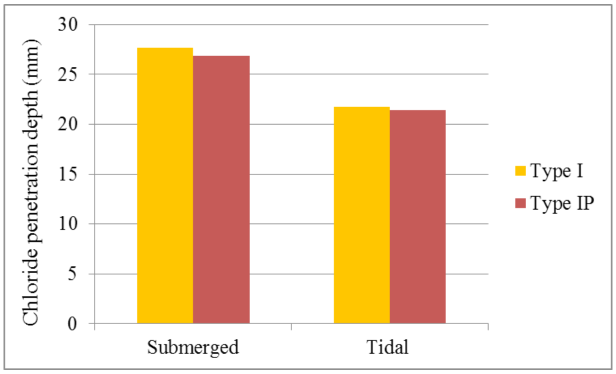

Figure 5. Chloride penetration depths in concrete specimens (w/c=0.65) exposed to submerged and tidal conditions

A regression analysis was performed to know whether the water-cement ratio and curing period have significant effect to the chloride penetration depth of concrete specimens as shown in Table 7.

Table 7. Regression analysis of the chloride penetration of concrete samples with water-cement ratio and curing period

Variable	df	Parameter Estimate	Std Error	Pr> [t]
Water-cement ratio	1	37.62435	4.22991	<0.0001***
Curing period	1	-0.10796	0.02297	<0.0001***

*** variables are highly significant at α = 1%

Results of the regression analysis show that increasing the water-cement ratio by 1% will yield to an increase in the chloride penetration of almost 37.62 units, holding other factors constant. Consequently, this implies that the lowering of the water-to-cement ratio from 0.65 to 0.55 led to a more significant decrease in chloride penetration depth in concrete specimens compared to changing the type of the cement used in concrete fabrication. The water-to-cement ratio has a very high influence on improving the resistance of concrete against chloride attacks, as found out earlier by Bouzoubaa, Zhang, & Malhotra (2000).

Conclusions

Type IP cement concrete specimens exhibited lower chloride penetration depths than Type I cement under the two types of exposure. This suggests that Type IP is more resistant to chloride penetration, which is most likely due to its fly ash components reacting with calcium hydroxide (CH) released during cement hydration and forming additional calcium-silicate-hydrates (C-S-H).

The study also shows that for bor both Type I and IP concrete, increase in the curing period and decrease in the w/c ratio enhanced the lowering of chloride penetration depths. Moreover, higher chloride penetration depths occurred in concrete specimens that were exposed to submerged condition compared to those exposed to tidal condition. Thus, effort must be done to provide more curing time period for all sub-structures exposed to marine environment than superstructure exposed to tidal conditions.

It is recommended that further study be done with curing periods beyond the standard 28 calendar days in order to determine the optimum curing time of concrete specimens that would yield the least chloride penetration depth. The findings would help establish minimum curing standards for structures exposed to marine environment other than the usual 28 days.

Acknowledgment

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