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Effect of Natural Pozzolan on Carbonation and Chloride Penetration in Sustainable Concrete

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***Abstract*— A study on green concrete as well as its durability is essential to promote the sustainable development of the concrete industry. Since the majority of concrete deterioration is connected to corrosion of reinforcement due to carbonation or chloride penetration into concrete, the influence of pozzolan through them must be investigated for concrete durability. This paper mainly focuses on the experimental study of the influence of Popa volcanic natural pozzolan on carbonation and chloride penetration process. The experimental tests are made on replacement of natural pozzolan 10%, 20%, 30% instead of cement and analysis show that optimized pozzolan replacement can promote on the mechanical strength of concrete along with time than reference concrete. According to the results, in the CO2 chamber and the natural condition, it contributes negatively to carbonation because the rate of carbonation increased as the amount of pozzolan increased. However, increasing the pozzolan content led to higher resistance of the concrete in chloride ion penetration.**

***Keywords*— carbonation; chloride penetration; cements; concrete durability; natural pozzolan**

I. Introduction

In Myanmar, Popa volcanic soil has been used in some construction projects such as dams and pavements to get high durability and to reduce construction cost. [1] The previous researchers said pozzolanic material has enough strength and high durability[2]-[4]. However, the adequate contamination ratio of Popa pozzolan for RC material is not established on theoretical basis. Carbonation is the result of the dissolution of CO2 in ate hydrate to form calcium carbonate (CaCO3) [5]-[7] The precipitation of calcium carbonate reduces the PH level of concrete [8]. When the pH of the solution decreased to 11.31, the surface became rough and large pits appeared because of the occurrence of localized corrosion [9]. Chloride ions can penetrate from the exterior if concrete is in contact with sea water or road structure in contact with de-icing salts. They can also the present in concrete from the very beginning, e.g., when calcium chloride is applied as an accelerator or when beach sand contaminated with salt is used as a fine aggregate [10].

Both carbonation and chlorides can lead to the breakdown of steel passivity and thus present a risk of loss of rebar cross-section and spalling of concrete cover owing to corrosion. This will affect both serviceability and safety of the structure [11]. So, it is needed to investigate the relationship among pozzolan content, water cement-ratio, concrete quality and external environment on carbonation rate and chloride penetration rate. The objective of this study is to experimentally investigate by measuring rate of carbonation and chloride penetration for different contamination ratios of pozzolan.

II. Material and Method

A. Material

In this research, ingredients for sustainable concrete are used from natural resource except for cement. Ordinary Portland cement, natural pozzolan, river sand, river shingle having a nominal maximum size of 19 mm and potable water are used in all mixes. The Popa Volcanic pozzolan, used in this research is obtained from in the middle portion of Myanmar. Its chemical properties are tested, and these compositions are shown in Table I. The details of aggregates are listed in Table II. The details of the chemical compositions and physical properties of Portland cement are listed in Table III and IV. The properties of used cement are satisfied for type I Portland cement.

The total percent of SiO_2, Al_2O_3, and Fe_2O_3 in pozzolan is higher than 70%. So, it is adequate for ASTM requirement for class N.

TABLE I
CHEMICAL COMPOPOPASITION OF POZZOLAN

Description	Percentage (%)	Requirements as per ASTM for Class N
CaO	16.224	SiO_2+ Al_2O_3 + Fe_2O_3= 70% (min)
SiO_2	31.639	
Fe_2O_3	40.594	
K_2O	9.485	
CuO	0.062	
SrO	0.489	
ZrO_2	0.063	
TiO_2	1.445	
Total	100	
Available alkalies	Nail	Max. 1.5
Loss on ignition (%)	2.26	Max. 10.00

TABLE II
PHYSICAL PROPERTIES OF AGGREGATE

Name of Test	Results	
	Coarse Aggregate	Fine Aggregate
Specific gravity	2.6	2.5
Absorption	0.56 %	0.8 %
Fineness Modulus	7.2	2.3
Dry-rodded Density of Coarse Aggregate (kg/m³)	1621	1363
Abrasion (%)	40.5%.	-

TABLE III
CHEMICAL PROPERTIES OF CEMENT

Description	Percentage (%)
CaO	67.927
SiO_2	12.8
Al_2O_3	2.3
Fe_2O_3	8.695
K_2O	7.534
SO_3	0.228
MnO	0.075
Other Total	0.441
All Total	100

B. Carbonation Chamber

To enable accelerated carbonation of concrete specimens, a CO_2 chamber was constructed. The CO_2 atmosphere was created using compressed CO_2 gas supply. A fan was provided in the chamber to circulate the CO_2 within the chamber. Specimen racks made of steel bars were provided on all four walls. In the chamber, air is conditioned to a CO_2 content of 3%, relative humidity (RH) of 65 to 95 % and temperature of 25 to 35 ºC.

TABLE IV
PHYSICAL PROPERTIES OF CEMENT

Name of test		Results	Specification (ASTM)
Specific Gravity		3.1	3.1-3.25
Fineness		6.2%	
Consistency		29%	
Setting Time	Initial	1hr 33min	> 60 min
	Final	3hr 50min	< 10 hrs
Compressive strength of cement mortar	3-day	12.2 Mpa	> 11.034MPa
	7-day	22.5 Mpa	>17.24MPa

Fig 1. Carbonation Test Chamber

C. Mixture Proportion

Four different concrete mixes have been prepared in this research: the first mix was made with 100% Portland cement (pozzolan 0%), the second mix was with 90% cement and 10% pozzolan (pozzolan 10%), the third mix was with 80% cement and 20% pozzolan (pozzolan 20%), and the final mix was with of 70% cement and 30% pozzolan (pozzolan 30%). All mixes are same water-cement ratio and equal fine and coarse aggregates. The details of mixture proportions are listed in Table V [12], [13].

D. Specimens Preparation and Test Methods

Hardened concrete specimens were tested for compressive strength (ASTM C 39) using 6 in³ cubes. Make 4in x 4in x 12in specimens to measure the depth of carbonation without Pozzolan and 10%, 20%, 30% cement replacement. The specimens were kept in their molds for 24 hours, and then they were demoulded and cured for 7 days in water. After curing, some specimens were transferred to the carbonation chamber and some were placed in laboratory's air. For measurement of the depth of carbonation, a PH indicator solution (made of 1% phenolphthalein in a 70% ethyl alcohol solution) was sprayed on the fractured surface of concrete specimens. After spraying this solution, the area that turned pink was considered non-carbonated, and the area that did not show discoloration was considered carbonated [5].

For chloride penetration test, 12in x 12in x 3.5in plain concrete slabs were prepared without Pozzolan and 10%, 20%, 30% cement replacement by Pozzolan according to ASTM C 1543. After slabs were moist cured for 14 days and stored in a drying room for 28 days, the sides of the slabs were coated with epoxy. And then slabs are ponding with 3 percent by mass NaCl solution. After the ponding period, samples are taken at four depths between 10mm and 65mm. These samples can be either cores or powder obtained after drilling with a rotary hammer-drill. Testing chloride percentage in concrete powder samples follows according to ASTM C 1152.

TABLE V
. MATERIAL COMPONENTS AND AMOUNTS USED TO PRODUCE CONCRETE SAMPLES

Component	Pozzolan replacement of cement				Specific Gravity
	0%	10%	20%	30%	
Cement (kg/m^3)	384	345.6	307.2	268.8	3.1
Pozzolan (kg/m^3)	0	38.4	76.8	115.2	2.8
Fine Aggregate (kg/m^3)	641	641	641	641	2.5
Coarse Aggregate (kg/m^3)	1113	1113	1113	1113	2.6
Water (kg/m^3)	180	180	180	180	1

Fig 2. Preparation of Samples for Carbonation Testing

(a) (b)

Fig 3. Preparation of Samples for Chloride Penetration Testing, (a) Slabs are Coated with Epoxy; (b) Slabs are Ponding with 3% NaCl Solution

III. RESULT AND DISCUSSION

A. Compressive Strength Test Results

In this research, we choose conventional concrete grade 25 and then mix with cement replacement material as pozzolan (10%, 20%, and 30%). Figure 4 shows compressive strength test results of pozzolan 0% to 30%.

According to experimental results, the compressive strength significantly developed when cement replacement by 0% to 20% pozzolan. Moreover, then, the compressive strength also increased when the age of concrete with pozzolan increased. In 30% pozzolan replacement, the compressive strength of concrete is slightly decreased than 20 % replacement. So, 20% of pozzolan replacement is optimized value for the highest strength of concrete than concrete without pozzolan.

TABLE VI
. AVERAGE COMPRESSION TEST RESULTS OF POZZOLAN 0% TO 30%

Pozzolan %	7 Day Average Strength (MPa)	28 Day Average Strength (MPa)	56 Day Average Strength (MPa)	90 Day Average Strength (MPa)
0	23.7	32.8	33.6	35.5
10	21.8	34.2	36.6	39.2
20	26.7	35.2	37.9	42.7
30	17.9	30.7	34.2	37.4

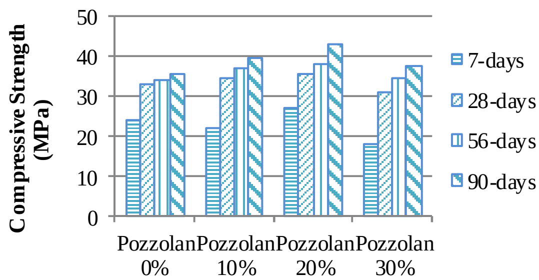


Fig 4. Comparison of Compressive Strength Test Results of Pozzolan 0% to 30%.

B. Carbonation Test Results in Natural Condition

At the end of the conditioning period, three concrete beams per each mix were split open and tested with phenolphthalein indicators to determine the area of carbonation. Specimens in the chamber were tested about 28 days, 56 days and 90 days interval. Carbonation area measurements of samples in the chamber at age 28 days, 56 days and 90 days are shown in Figure 5, Figure 6 and Figure 7 respectively. Figure 8 show comparison of carbonation area percentage.

Concrete made without pozzolan did not appear in carbonation at all age. Figure 8 indicated that the area of carbonation was significantly increased when concrete mixed with pozzolan 10%, 20%, and 30%. The area of carbonation increased as the amount of pozzolan increased. The rate of carbonation was highest in concrete made with 30% cement replacement by pozzolan at all age. Therefore, carbonation depends on pozzolan percentage and age of concrete.

(a) Pozzolan 0% (b) Pozzolan 10% (c) Pozzolan20% (d) Pozzolan30%

Fig. 5. Carbonation Area Measurement of Samples in Chamber at Age 28 Days

(a) Pozzolan 0% (b) Pozzolan 10% (c) Pozzolan20% (d) Pozzolan30

Fig. 6. Carbonation Area Measurement of Samples in Chamber at Age 56 Days

(a) Pozzolan 0% (b) Pozzolan 10% (c) Pozzolan20% (d) Pozzolan30

Fig 7. Carbonation Area Measurement of Samples in Chamber at Age 90 Days

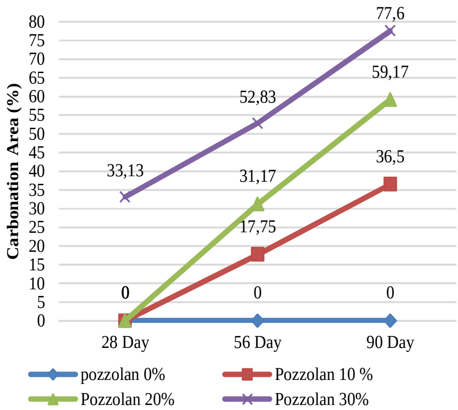
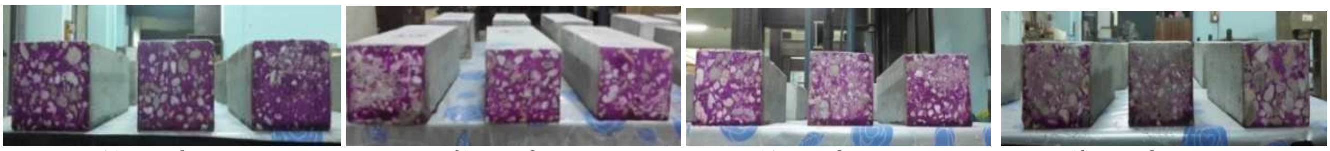


Fig. 8. Comparison of Carbonation Area Percentage

C. Carbonation Test Results in Chamber

After 3 months and 6 months in the natural condition, samples were also split open for reading carbonation areas. The dry surfaces of samples were sprayed with 1% solution of phenolphthalein in alcohol. Moreover, then, the areas of carbonation were measured and numerically averaged. Figure 9 and Figure 10 show carbonation area measurement of samples in natural condition at age 3-month and 6-month. Figure 11 show comparison of carbonation area percentage in natural condition.



(a) Pozzolan 0% (b) Pozzolan 10% (c) Pozzolan20% (d) Pozzolan30

Fig 9. Carbonation Area Measurement of Samples in Natural Condition at Age 3-Months

(a) Pozzolan 0% (b) Pozzolan 10% (c) Pozzolan20% (d) Pozzolan30

Fig 10. Carbonation Area Measurement of Samples in Natural Condition at Age 6-Months

At age 3 months, concrete made without pozzolan did not show carbonation. Samples made with pozzolan 10% and 20% did not appear too much difference in carbonation. The carbonation area for 30% pozzolan instead of cement was found to be more than that of 10% and 20% replacement level. After 6 months period, pozzolan 0% samples were started to carbonation. The carbonation area increased when the amount of pozzolan increased.

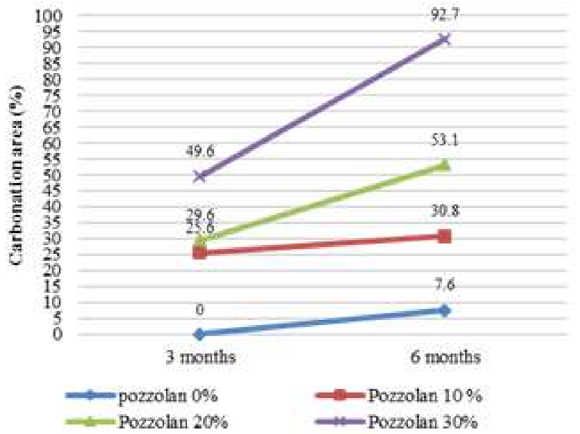


Fig 11. Comparison of Carbonation Area Percentage in Natural Condition

D. Compressive Strength Results after Carbonation

After carbonation, samples from carbonation chamber are cut and tested compressive strength. Compressive strength results after carbonation of pozzolan 0% to 30% are shown in Table 7 and comparison of compressive test results after carbonation of pozzolan 0% to 30% as shown in Figure 12.

According to these results, the more substantial pozzolan contents, the more carbonation increased and the less the compressive strength along with time.

E. Chloride Penetration Test Results

After 28 days, 56 days, 90 days ponding period, samples are taken at five depths between 0.5 in and 2.5 in. The chloride data results after 28 days, 56 days and 90 days ponding periods are shown in Table 8. Chloride contents in different pozzolan replacement are compared in Figure 13, Figure 14 and Figure 15 respectively

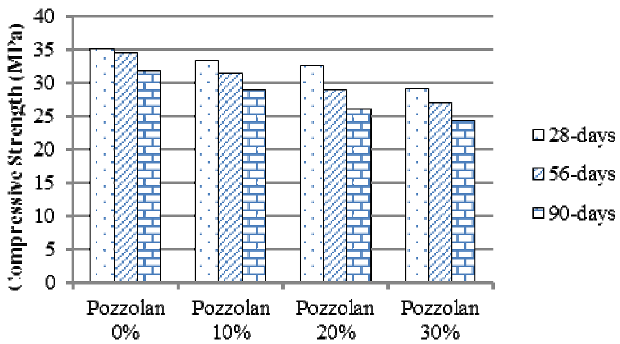


Fig 12. Comparison of Compressive Test Results after Carbonation of Pozzolan 0% to 30%.

TABLE VII
COMPRESSIVE STRENGTH RESULTS AFTER CARBONATION OF POZZOLAN 0% TO 30%

Pozzolan (%)	28 Day Average Strength (MPa)	56 Day Average Strength (MPa)	90 Day Average Strength (MPa)
0%	35.1	34.6	31.8
10%	33.3	31.5	28.9
20%	32.5	28.9	26
30%	29.2	27.1	24.4

TABLE VIII
CHLORIDE CONTENT, % BY MASS OF CONCRETE AFTER PONDING PERIOD

Age	Depth	Plain	Pozzolan 10%	Pozzolan 20%	Pozzolan 30%
28 Days	0.5 in	0.12	0.18	0.18	0.18
	1.0 in	0.12	0.12	0.12	0.12
	1.5 in	0.12	0.12	0.12	0.12
	2.0 in	0.12	0.12	0.12	0.12
	2.5 in	0.12	0.12	0.12	0.12
56 Days	0.5 in	0.24	0.24	0.2	0.23
	1.0 in	0.24	0.21	0.17	0.17
	1.5 in	0.21	0.21	0.18	0.15
	2.0 in	0.21	0.19	0.18	0.15
	2.5 in	0.19	0.17	0.14	0.12
90 Days	0.5 in	0.36	0.32	0.29	0.26
	1.0 in	0.36	0.29	0.29	0.2
	1.5 in	0.29	0.29	0.26	0.18

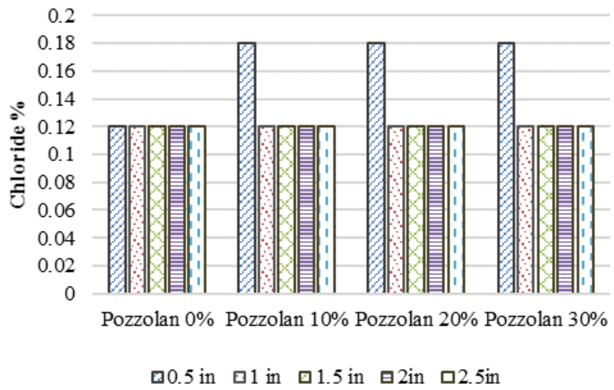


Fig. 13. Chloride Content after 28 Days Ponding Period

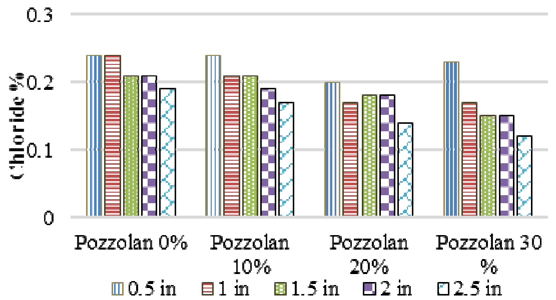


Fig. 14. Chloride Content after 56 Days Ponding Period

After 28 days ponding period, chloride contents of the conventional concrete without pozzolan are same for all depths. In cement replacement by pozzolan (10%, 20%, and 30%), the chloride contents at 0.5 in depth are higher than the other depths. It can be initial absorption effect of pozzolana concrete. After 56 days and 90 days ponding period, the chloride contents for all concrete decreased when the depths increased. Chloride ion penetration slightly decreased when the amount of pozzolan increased.

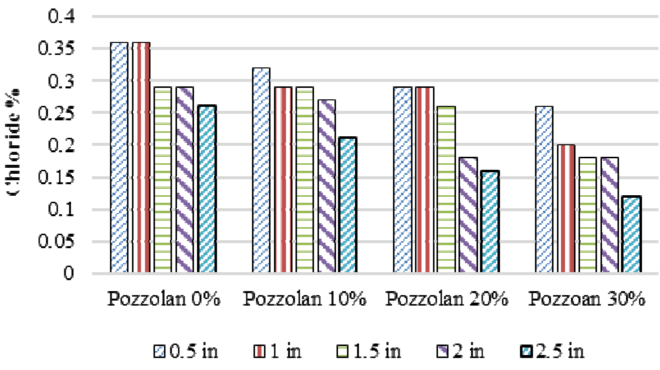


Fig. 15. Chloride Content after 90 Days Ponding Period

IV. Conclusions

According to the results of this investigation which have been discussed above, the following conclusions can be drawn. The compressive strength developed at age 28 days when the replacement percentage of cement by pozzolan increased to 20% instead of cement than without pozzolan. So, 20% of pozzolan replacement is optimized value for the highest strength of concrete than concrete without pozzolan.

The compressive strength also increased when the age of concrete with pozzolan increased till 90 days, the experimental time. The chloride ion penetration slightly decreased when the amount of pozzolan increased. The rate of carbonation increased as cement replacement by pozzolan increased from 0 to 30%.

The compressive strength of concrete has been reduced because of carbonation process. The compressive strength more decreased when the time of carbonation longed. For considering long-term durability, the larger amount of supplementary cementing materials such as pozzolan should not be used in RC structures without the testing rate of reinforced steel corrosion because it can be increased the area of carbonation, although pozzolan is suitable for plain concrete structures such as dam, pavement. However, used pozzolan instead of cement is suitable for marine environment structures because it can reduce the chloride penetration.

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