Journal of Structural Engineering and Geotechnics,
8 (1), 55-67, Winter 2018

Investigation of mechanical and durability properties of lightweight concrete containing Pumice

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Received 15 October 2017, Accepted 09 February 2018

Abstract

In this research, the effect of the cement, sand, and pumice mixture on the durability of lightweight concrete is investigated. The intention of this paper is to replace a certain amount of the pumice percentage as an alternative option of the cement and pumice sand aggregate with conventional sand components. The experimental results include compressive strength, ion-chloride emission factor (RCPT and RCMT). The experiments are carried out at the concrete age of 28 and 90 days. The results indicate that pumice composition improves the durability of lightweight concrete. Furthermore, it was observed that the proposed mixing design have proper permeability resistance against the chloride ion attack. For 90 days aged concrete, it was notified that the samples had a chlorine ion penetration coefficient of 10% which is less than the concrete specimens of 28 days. Finally, the compressive strength of the new mixing design samples can be increased by 1.5 to 2.5 Mpa after 90 days.

Keywords: Lightweight concrete, Pumice, Chlorine ion, compressive strength, RCPT, RCMT

1. Introduction

A method for measuring the penetration of chloride ion in concrete is RCPT. This method is an ASTM C1202 [1] standard currently considered as a quality control method for concrete in Persian Gulf conditions in Iranian technical documents. In general, the main reasons for the use of light concrete can be reducing the load on the structure, thereby decreasing the effective force of earthquakes and other lateral loads; completing and extending structures such as bridge decks; and increasing the traffic capacity without changing the structure of the structure under construction. The lifetime of the structures, the sound insulation, and the thermal properties most suitable for use in buildings are increasing [2]. Reduces the earthquake force in the building, and in addition to raising the level of seismic safety, structural members' dimensions, such as beams, columns, and shear walls, are reduced. Ion chlorine is among the most important causes of steel corrosion in reinforced concrete in corrosive environments, especially on coasts such as the Persian Gulf and Oman Sea. Many factors affect the level of chlorine ion penetration in concrete, which can be summarized as concrete quality [3]. The main reasons for the application of lightweight concrete can be summarized as follows:

reducing the load on the structure and, as a result, reducing the force of effective earthquake and other lateral loads decreasing structural and non-structural dimensions, thus increasing the architectural space of the building-.Use of lightweight concrete for strengthening or expanding structures such as bridge decks to increase traffic capacity without changing the foundation of structures enhancing the load capacity of structures sound and thermal insulation, suitable for use in buildings such as hospitals and schools resistance to fire hazard Increasing the run speed Possibility of building high structures in dense areas Construction of prefabricated components "Light concrete" for the implementation of structural and non-structural components Light aggregates are grains that are low due to porosity and their spatial weight. Lightweight beads are used to produce lightweight

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concrete, light insulation, lightweight concrete blocks, lightweight mortars, and lightweight aggregates, in order to fill empty spaces for light, thermal, and sound insulation [4].

2. Lab program

2.1. Materials used

Broken coarse grains with the maximum nominal size of 19 mm have been used to manufacture concrete mixtures from Portland cement type 2and natural aggregates. Gravel with a diameter greater than 4.75 mm, sand of less than 4.75 mm in diameter have also been employed. Pumice aggregate was obtained from the mixing plan in the Qorveh mine of Sanandaj, Iran, and from Qazvin, Iran. (Figure 1)

Figure 1. Pumice passed from sieve No. 4

2.2. Concrete mix design

According to Table (1), the water-cement ratio control was kept variable in this study and the maximum cement content of 413.0 Kg/m³, minimum cement content of 344.26 Kg/m³ were employed. Moreover, the amount of sand used in the first design was 100% of sandstone pumice. In the second mixing plan, ordinary sand was utilized instead of pumice sand. The slump test range was a maximum of 70mm (P5A) and the minimum belonged to P2A. In the first lightweight concrete is used today more widely in the construction process. Lightweight concrete is cheaper than ordinary concrete. Concrete structures that have a compressive strength of more than 17-45 MPa due to having a weight of less than 2000. Generally [5], the main reasons for the use of light concrete can be reducing the load on the structure, thus decreasing the effective force of the earthquake and other lateral loads; retrofitting and expansion of structures such as the deck of bridges without changing the foundation of the structures; increasing the load capacity of structures; and sound and thermal insulation. Pumice is one of the oldest lightweight structures used in structures. Pumice has hollow holes caused in the course of volcanic activity and the release of gases from cooled magma [6]. Regarding chlorine ion concentration, experiments such as AASHTO T259 and ASTM C1556 [7] have been conducted based mainly on the measurement of chlorine and calcium at different levels of concrete exposed to sodium chloride solution [8]. Due to the decrease in the chlorine ion penetration phenomenon in concrete and the time of recent experiments, the use of rapid methods has always been considered for convenient concrete quality control [9, 10]. One of the most common methods for evaluating the permeability of design is through reducing the steppe of cement mortar and sand, changing the compressive strength test, rapid ion-chloride transfer (RCMT), and rapid ion-chloride penetration testing (RCPT) [11].

Table 1. Mix design

Design name	Sand weight($\frac{kg}{m^3}$)	Gravel weight($\frac{kg}{m^3}$)	Cement weight($\frac{kg}{m^3}$)	Water weight($\frac{kg}{m^3}$)	Water to cement %ratio
P1A	706.93	701.49	400	190	0.48
P2A	668.625	668.625	387.75	190	0.49
P3A	660.03	660.03	372.54	190	0.51
P5A	594.39	594.39	396.22	210	0.53
P6A	490.87	490.87	344.26	210	0.61
P1B	575.97	806.46	413.04	210	0.46
P2B	575.97	735.19	403.84	190	0.48
P3B	575.97	692.19	403.84	210	0.52
P4B	575.97	575.97	362.06	210	0.58

2.3. RCPT

This test is based on the ASTM C1202 standard [11, 12] and its duration is 6 hours. A major problem in the durability of reinforced concrete structures is the corrosion of steel reinforcements due to chlorine ion penetration into concrete. Accordingly, an accurate assessment of concrete strength against chlorine ion penetration is required to achieve durable structures. Due to the slow nature of chloride ion penetration in concrete, long time, and the cost of recent experiments, the use of rapid methods has been considered to facilitate the quality control of concrete. A common method for evaluating the permeability of concrete against chlorine ion is the RCPT. This method has the ASTM C1202 standard and is currently considered as a quality control method for concrete in the conditions of the Persian Gulf and noted in the technical documents of Iran. The test was placed inside the desiccator (vacuum) for 3 hours. Then, it was removed by vacuuming the air pump inside the desiccator. In this case, the specimens in vacuum conditions also release air.
After this step, the drainage valve into the container is opened to allow the tank to be filled with water (no air is allowed at this stage). All the specimens will dip into the water, and this takes 1 hour. After 4 hours, the pump is switched off by vacuuming the pump while the specimens are immersed in water, allowing the water to enter the desiccator. The specimens remain in the desiccator for 18 hours. In general, the preparation of samples in the same compartment as the vacuum takes 22 hours (Figures 2).

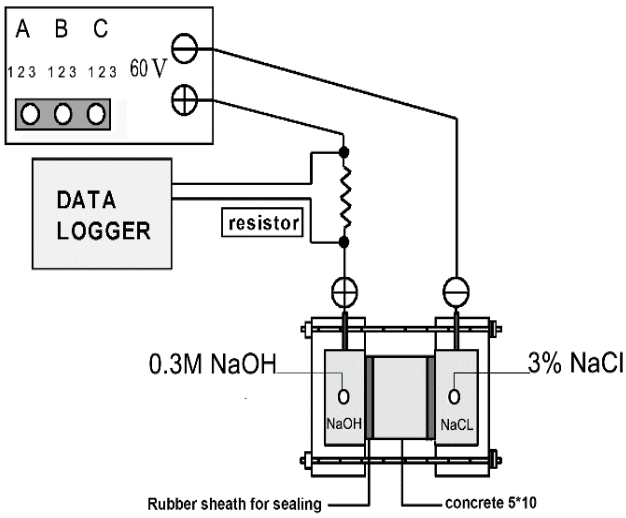

Figure 2. Schematic view of the RCPT device.

2.4. RCMT

This method is based on the AASHTO TP 64 standard [13, 14]. First, the device enters a circuit initial voltage of 60V, and then, in accordance with the flow of samples, the flow in each interval is applied according to the final voltage. This voltage remains constant until the end of the test period. The duration of the test is also specified in the table. A rapid method of ion chloride penetration with good performance and acceptable results in the long term is the RCMT. Based on standards, RCMT is generally similar to RCPT. In this method, in order to prevent the sample from warming during the test, the voltage applied to the sample is changed according to the flow of the sample and the volume of the salt solution in contact with the sample is significantly increased. Also, in RCMT, to prevent the effect of other ions in vapor solutions on the test result, instead of measuring the flow path, the depth of the penetration of chlorine ion into the specimen, breaking through the Brazilian stretch of resistance, and after testing and spraying The soluble reagent (silver nitrate) is determined in it. In this research, the AASHTO TP 64 standard was used for testing [7] (Figures 3-5).

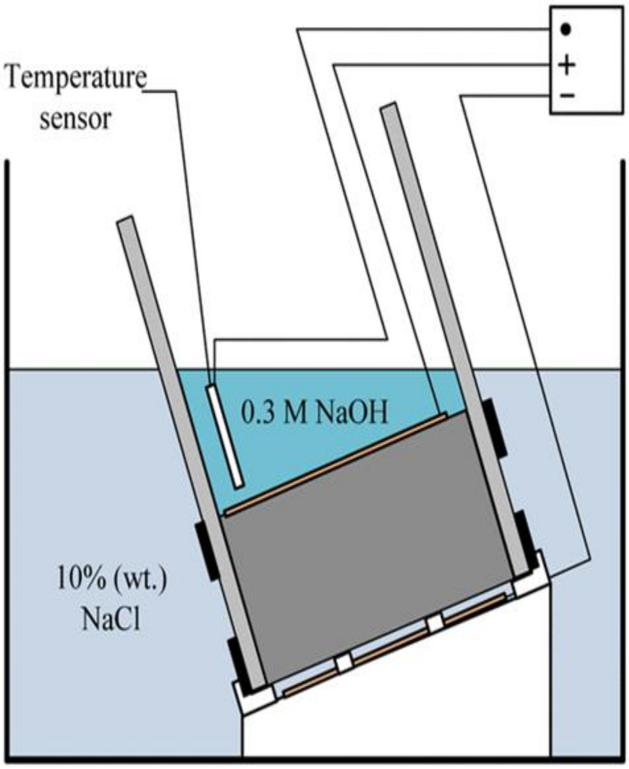

Figure 3. Schematic view of the RCMT device.

$M = \frac{h}{Vt}$ (1)

Where

M = chlorine ion penetration rate
h = mean chlorine ion penetration depth in millimeters

t = test time in hours

V = applied voltage

2.5. Testing the compressive strength

As described and based on Table (1), the light concrete mixing plan has two designs: A containing 100% pumice aggregate, and B used sand instead of pumice sand.
Then, the concrete was made of 10*10*10 cubic shapes and 10*20 cylindrical molds, opened after 22 hours, and broken with a concrete jack of 300 tons [15].

Figure 4. Cutting of 10*20 concrete cylindersto concrete slices smaller that 5*10according to the standard.

Figure 5. Concrete cutters 5 * 10, in vacuum machine.

3. Results and analysis of tests

As described in the experimental section, the specimens were subjected to two sections (under the influence of chlorine ion and pond with normal water) according to Table 1. It is known that the cement rate increases the compressive strength of 10*10*10 specimens, and the lowest grade showed the most economical response in this project. The compressive strength of samples sampled under the influence of chloride ion showed a 1-1.5 MPa drop in resistance. Pumice fine grain aggregation enhancement has caused the concrete sample under pressure to exhibit a significant degree of ductility, showing less damage while standing under the concrete breaker jack. Based on the figure and diagram of the following page, it was found that increasing the compressive strength by 1-1.5 MPa in 90 days (Figures 6, 7). In Figure 7, the usual sand is replaced by pumice sand as we know that fine-grained sand provides a better adhesion between cement mortar and sand used as pumice. Precision in the correct selection of the granularity and uniformity of seeds increases the resistance of concrete specimens. As explained, the design was measured on Days 28 and 90, and samples of chlorine ion were in accordance with the standards of Iran's Concrete Code 9. In the RCPT, the penetration rate of the design, called P6A, which absorbed the highest amount of ion chloride penetration, was found. The rest of the designs differ by roughly 100. In RCMT, the lightest design with a relatively good compressive strength, P6A showed the highest penetration of chlorine ion. Moreover, the lowest rate of ion chloride penetration belongs to a design called P1A. It can be ascertained that the penetration of chloride ion into the 90-day test is slightly more difficult. However, the disadvantages are whether areas that are under the influence of ions and sulfates can be sheltered or protected for up to 90 days by the relevant structures in relation to the attack of these materials in nature. To have a structure that reaches its ultimate resistance and shows less influence over ions.

The mixing design in Table 1, PA, is from (1 to 5) whose compressive strength is in this figure. Compressive strengths of 28 and 90 days have been investigated under water conditions containing chlorine ion and drinking water.

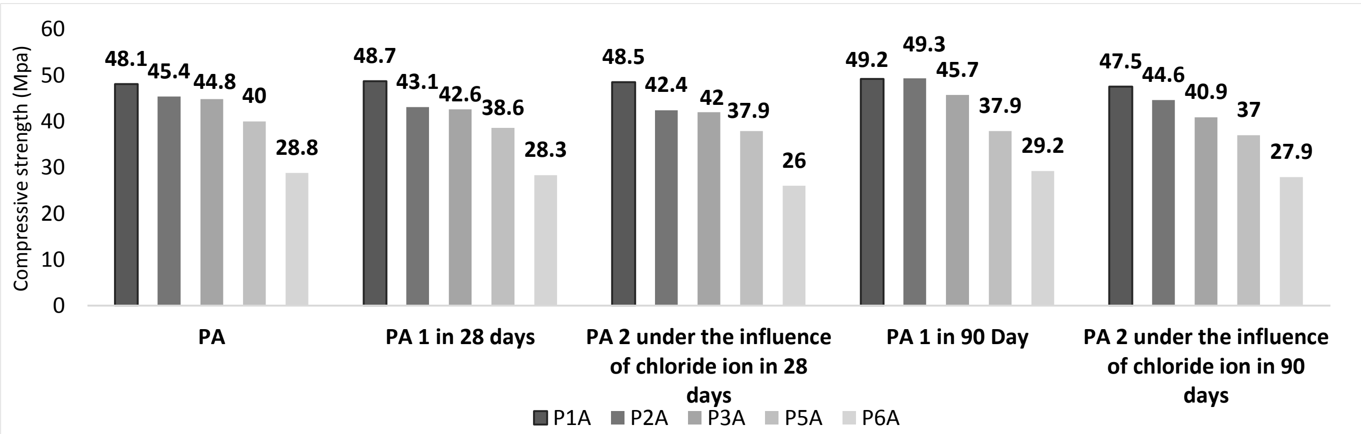

Figure 6. Results of the test of the compressive strength of the PA.

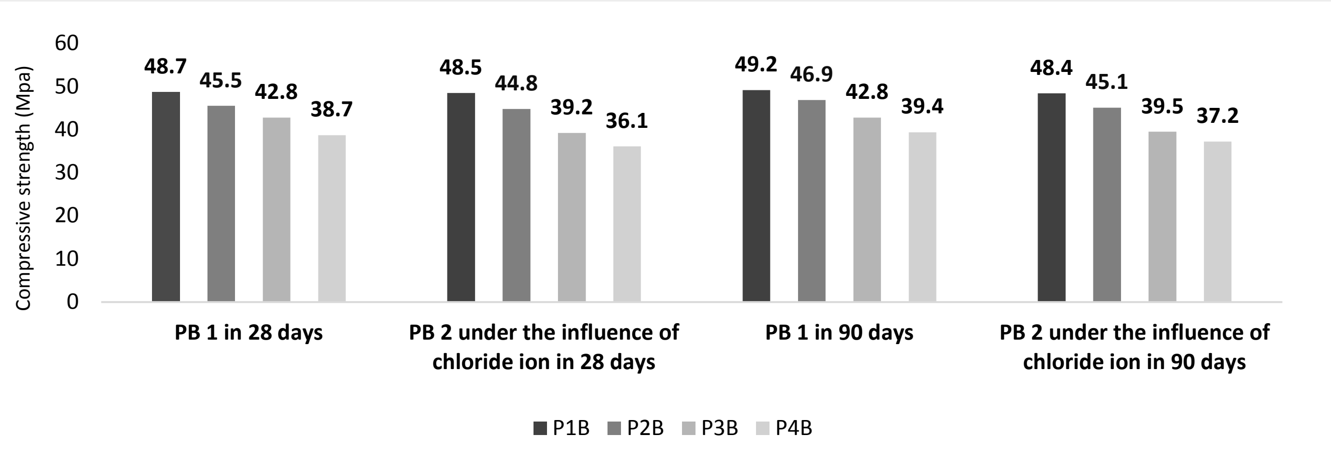

Figure 7. Results of the test of the compressive strength of the PB.

The mixing design in Table 1, PB, is from (1 to 4) whose compressive strength is in this figure. Compressive strengths of 28 and 90 days have been investigated under water conditions containing chlorine ion and drinking water. (Figures 8, 9)

Figure 8. Sample failure with a 300-ton jack.

Figure 9. Specific gravity of light concrete (P6A).

In this table 2, the results of the RCPT are presented. In the left column and right columns, the results of Days 28 and 90 are respectively shown.(Figure 10.)

Based on Figures (11-14), P6A demonstrates the highest level of chlorine ion penetration.

In contrast to the light weight and good resistance during the test of compressive strength, it can be said that the penetration is ideal in Figure's (11-14). In Figures (11, 14), it can be seen that with the age of concrete and 90-day care it reduces the penetration of chloride into the concrete, as well as increases the life of the concrete.

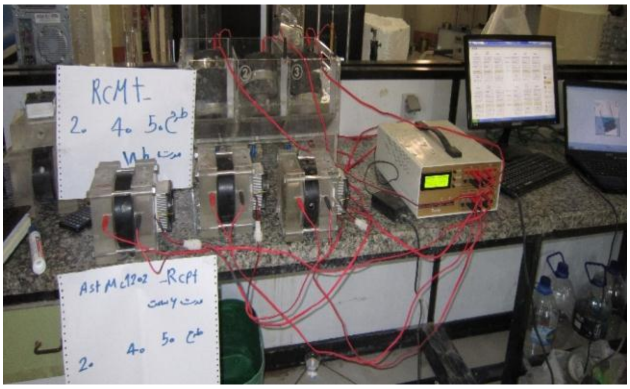

Figure 10. General Test of chloride ion penetration in concrete.

Table 2. Result of the RCPT

RCPT TEST (PA) 28 day		RCPT TEST (PA) 90 day	
name	Columb	name	Columb
P2A	3644.89	P2A	3546.34
P3A	3846.27	P3A	3721.02
P5A	4589.77	P5A	4554.07
P1A	3470.64	P1A	3318.36
P5A	4366.53	P5A	4268.07
P6A	4461.12	P6A	4351.78

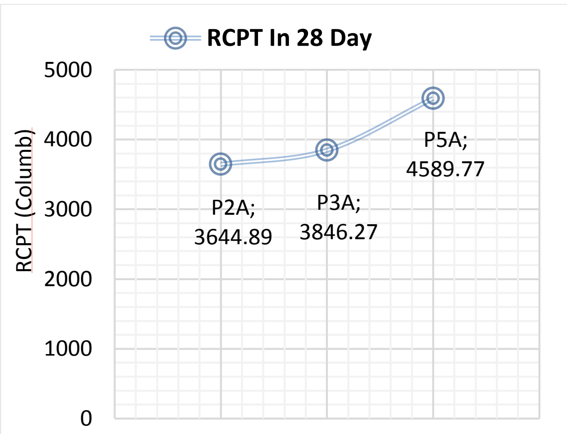

Figure 11. The amount of chlorine ion penetration, the transfer value from P2A, P3A, P5A is shown as a curve. Considering the cement content and the weight of gravel, sand and the amount of chlorine ion penetration in concrete.

In these Figures, the level of chlorine ion penetration is shown. The penetration rate with a curve shows which plan has the most and which design has the least amount of chloride ion penetration. According to Table 1, the Mix design.

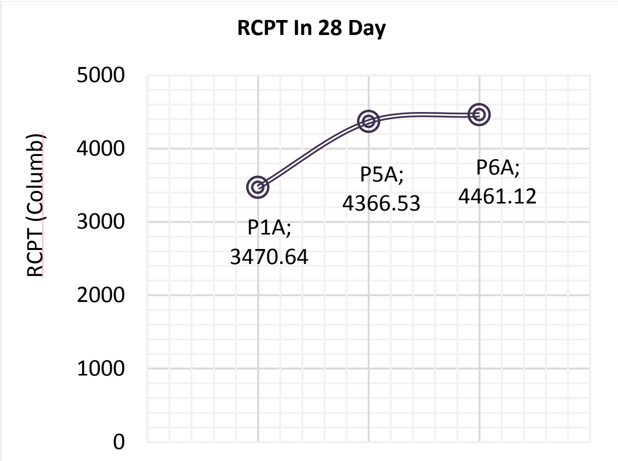

Figure 12. The amount of chlorine ion penetration. The transfer value from P1A, P5A, and P6A is shown as a curve, considering the cement content and the weight of gravel, sand, and the amount of chlorine ion penetration in concrete.

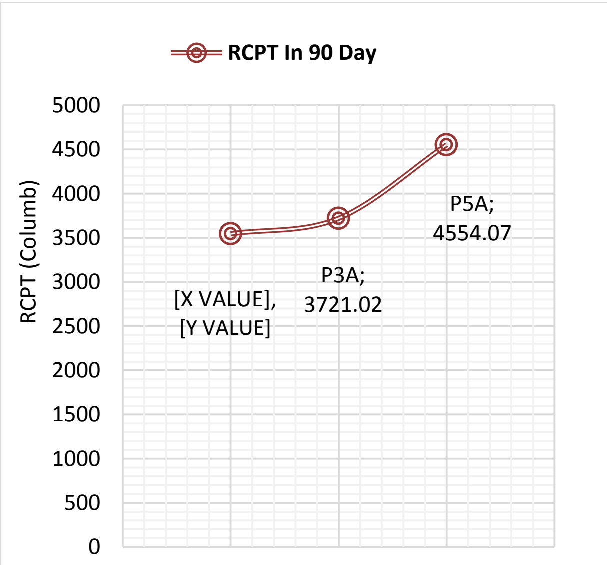

Figure 13. The amount of chlorine ion penetration. The transfer value from P2A, P3A, and P5A is shown as a curve, considerig the cement content and the weight of gravel, sand, and the amount of chlorine ion penetration in concrete.

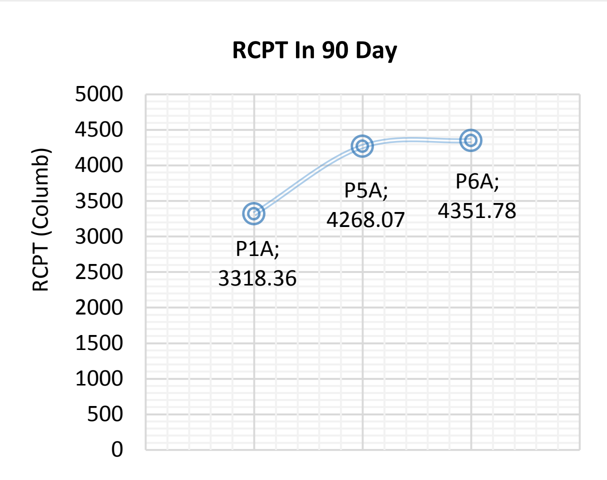

Figure 14. The amount of chlorine ion penetration, The transfer value from P1A, P5A, P6A is shown as a curve. considering the cement content and the weight of gravel, sand and the amount of chlorine ion penetration in concrete.

4. Test results (RCMT, 28- and 90-day)

As already explained, the standard for the RCMT test is A ASHTO TP 64. According to the same formulae, the clock, voltage, and failure modes have been investigated. The figure 15, clearly shows the depth of penetration of chlorine ion by RCMT. The chloride ion penetration region in the concrete is the same region exposed to NaCl or laboratory salt. After exiting the test pieces, breaking the specimen of the Brazilian cylindrical specimen, and inlaying the inner surface of the concrete, the area under the influence of NaCl depicts a purple- silver color, indicating the degree of penetration of chloride ion. (Figures 16-23), table 3.

Table 3. presents the degree of chloride ion penetration in the accelerated transition RCMT chlorine ion test.

RCMT ion chloride penetration $(\frac{mm}{V*hr})$			
90 Day		**28 Day**	
0.01227	**P2A**	0.01527	**P2A**
0.01377	**P3A**	0.01407	**P3A**
0.01294	**P5A**	0.01324	**P5A**
0.01432	**P1A**	0.01314	**P1A**
0.01192	**P5A**	0.01222	**P5A**
0.0182	**P6A**	0.01850	**P6A**

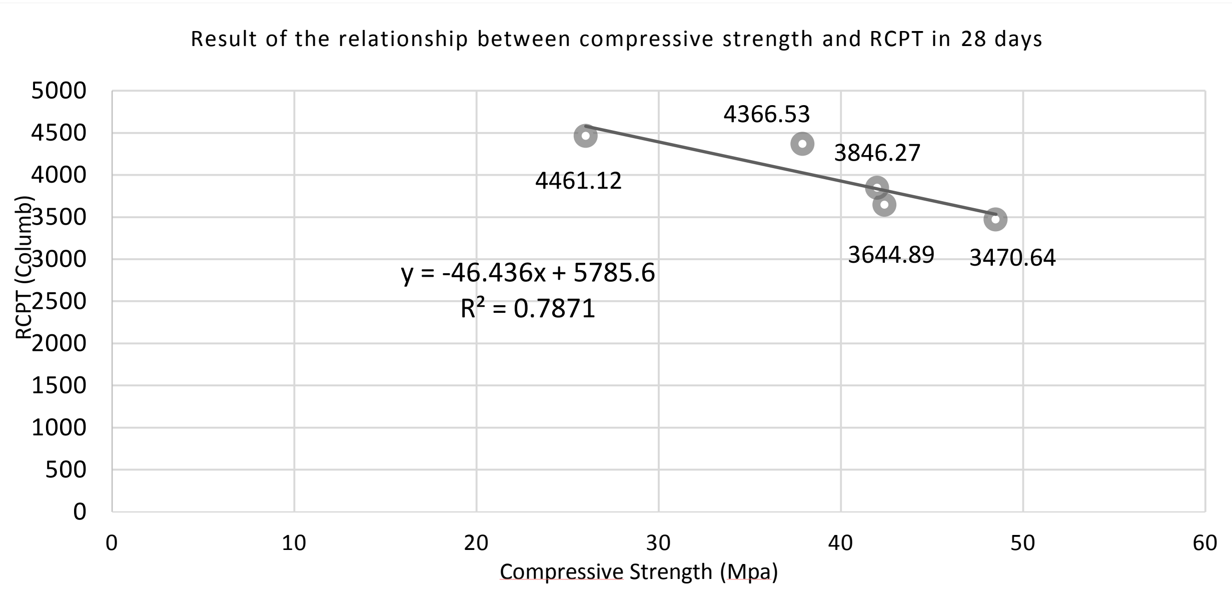

Figure 15. High correlation between results of PA RCPT and compressive strength.

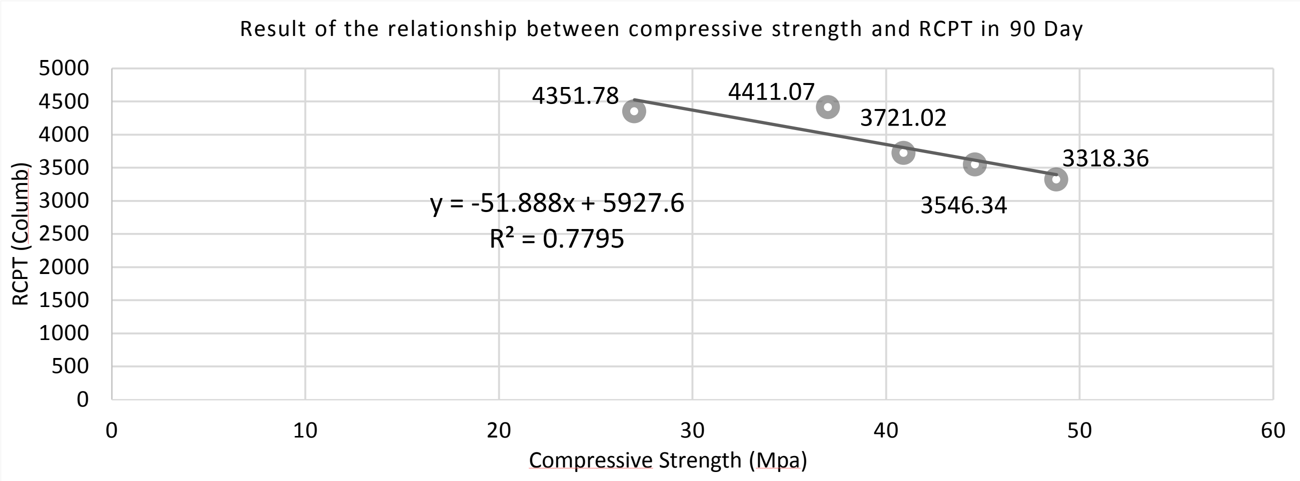

Figure 16. High correlation between results of RCPT and compressive strength.

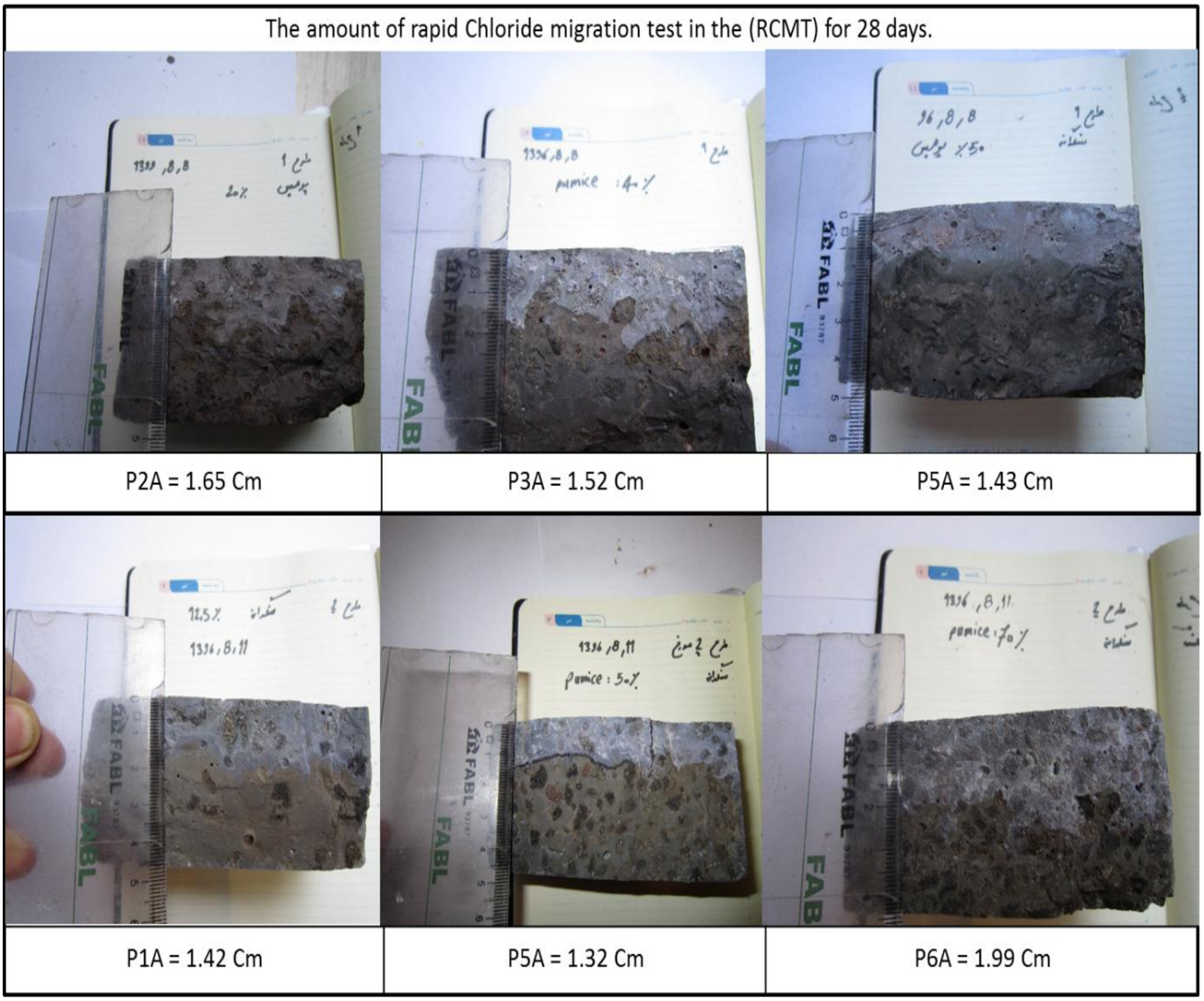

Figure 17. The amount of RCMT for 28 days.
The degree of penetration depth in these concrete specimens is visible.

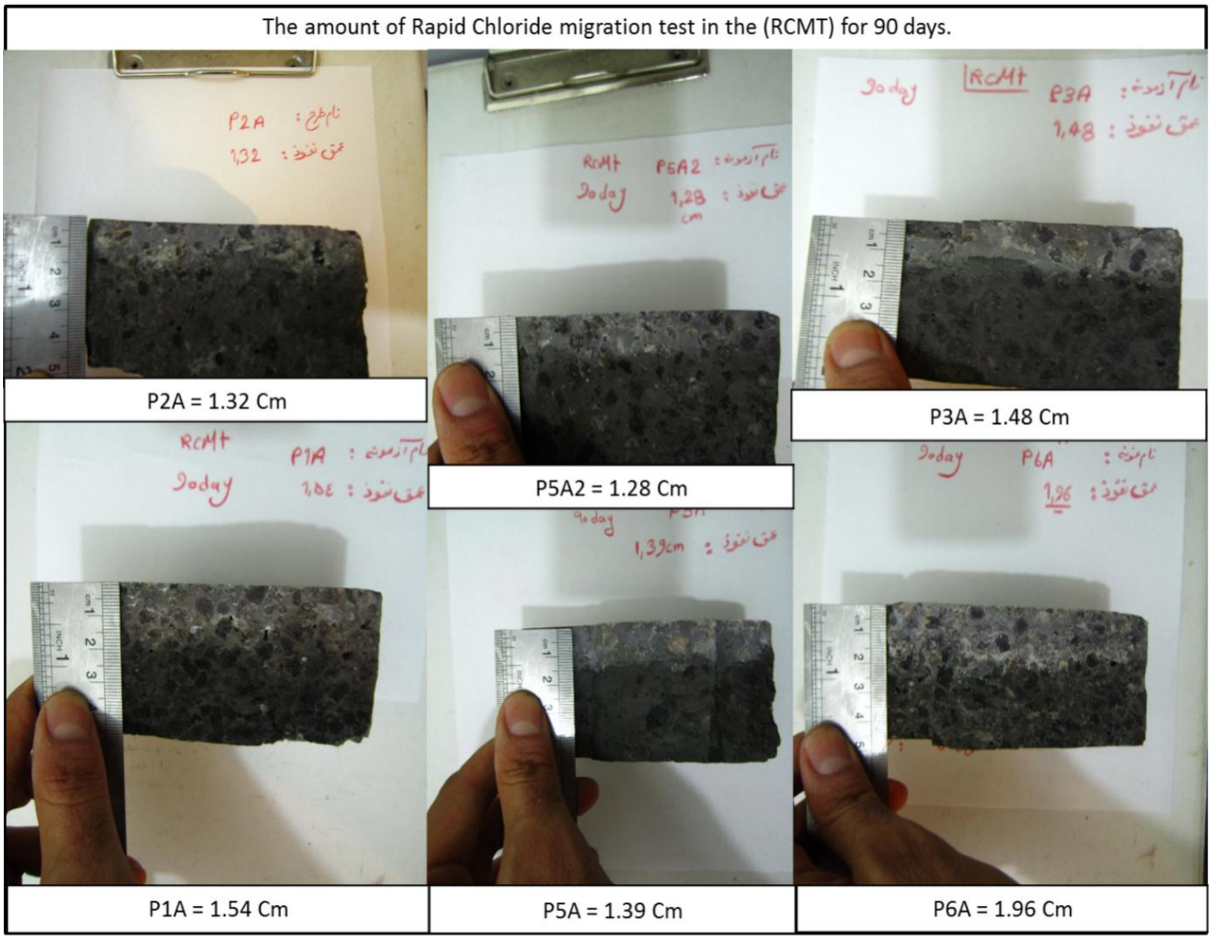

Figure 18. The amount of RCMT for 90 days.
The degree of penetration depth in these concrete specimens is visible.

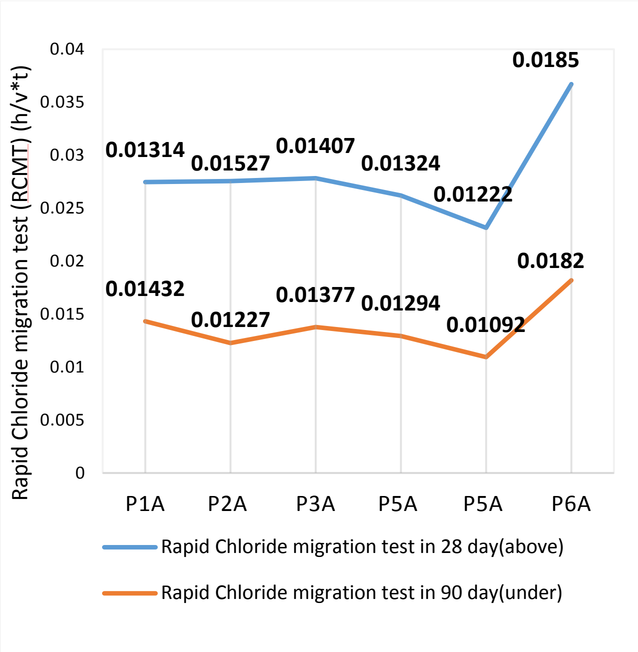

Figure 19. The amount of chloride ion in RCMT.

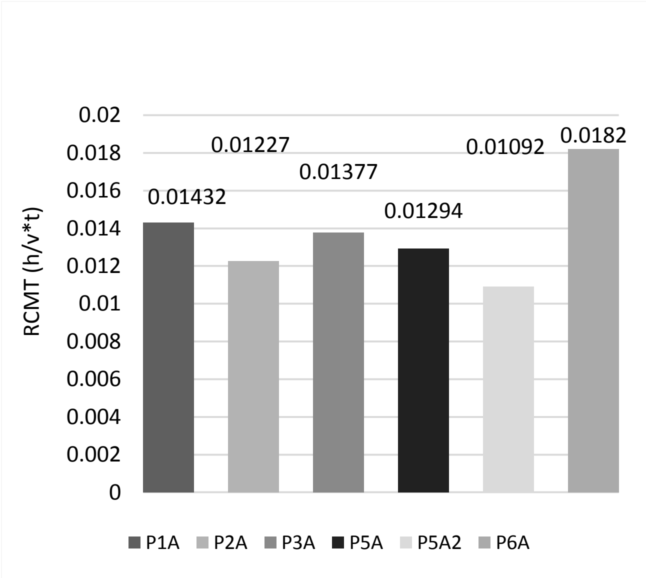

Figure 20. RCMT on day 90.

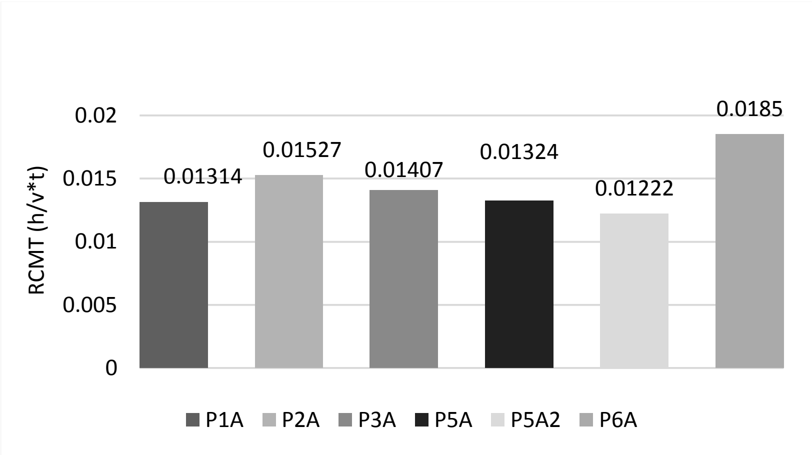

Figure 21. RCMT on day 28.

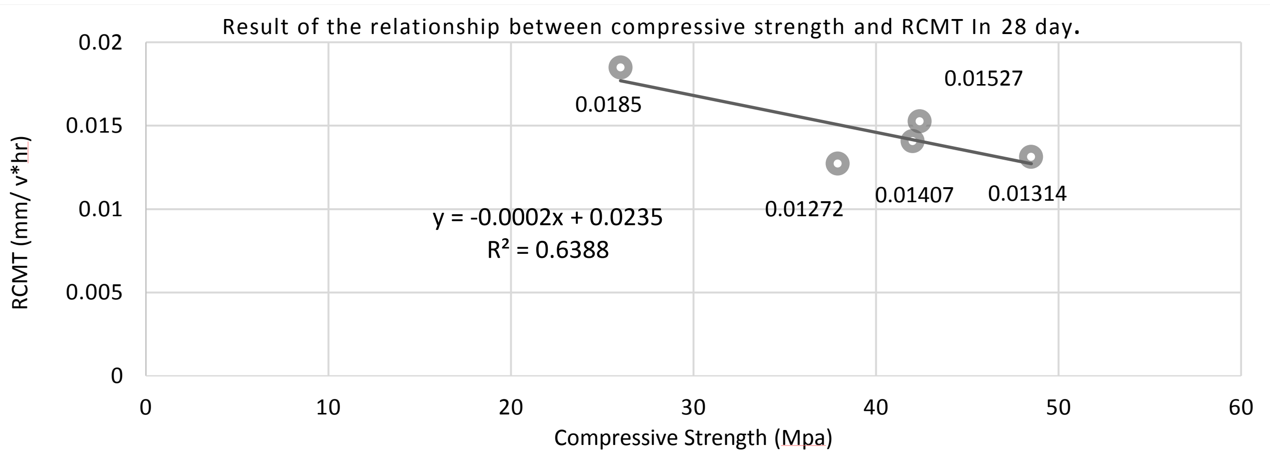

Figure 22. Relationship between compressive strength and RCMT on Day 28.

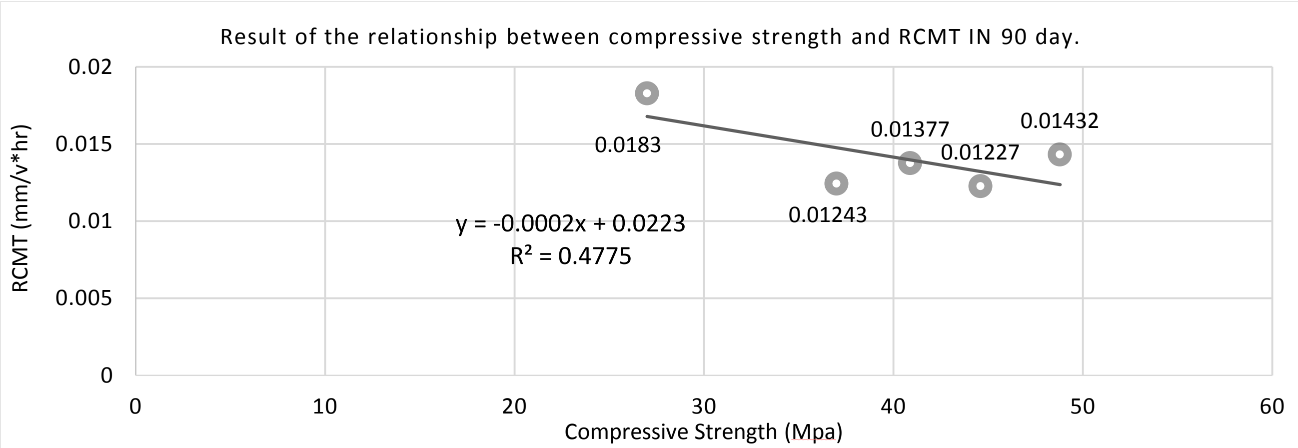

Figure 23. Relationship between compressive strength and RCMT on Day 90.

5. Conclusions

The uniformity of grains (sand and gravel), the optimal amount of water, and the amount of cement consumption economically in the design of precursors, as well as the care of concrete up to 90 days against factors such as chloride ion attacks, increase strength and maintain durability concrete turns.

The best content of cement is 400 kg / m³.

The best P5A designs have a weight of 1742 kg/m³ and a design of P4B 1724 kg/m³. Therefore, the water-to-cement ratio is affordable, and both the strength and cost of construction as well as the influence of chlorine ion and chemical interactions are the lowest.

By replacing pumice with ordinary sand, compressive strength can be increased by 1.5- 2.5 MPa. In other words, by replacing pumice with ordinary sand, the resistance of the test piece can be increased by 25%-30%.

In general, RCPT had a better performance and efficiency compared to RCMT. Thus, RCPT has a faster and better performance than RCMT. In RCMT, however, the results were objectively visible.

According to AASHTO TP 64 standards, cylindrical specimens were exposed to chemical interactions for 18 hours, leading to a higher penetration precision over a longer time compared to the RCPT method.
In order to achieve a more complete fit, in the P6A design with the weight of 1539.3 kg/m3, chemical interactions cannot have a significant impact on permeability of the other mixing designs.

The chlorine penetration rate in the P6A design with 300 kg/m³ in RCMT was 0.0185 (mm/h), superior to the experiments in previous studies.

6. Acknowledgment

Thanks to the concrete research center of Islamic Azad University of Qazvin.

7. References

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