Contents lists available at **CEPM**

Computational Engineering and Physical Modeling

Journal homepage: www.jcepm.com

The Effect of Zeolite on Different Mechanical Properties and Permeability of Self-Compacting Concrete

F. Pirmohammadi Alishah

Assistant Professor of Civil Engineering Department, Shabestar Branch, Islamic Azad University, Shabestar, Iran

Corresponding author: *Petrofarhad@iaushab.ac.ir*

https://doi.org/10.22115/CEPM.2020.214817.1079

ARTICLE INFO

Article history:
Received: 06 January 2020
Revised: 10 March 2020
Accepted: 09 April 2020

Keywords:
Pozzolan;
Cement;
Mechanical properties;
Permeabili;
Water absorption rate.

ABSTRACT

Today using alternative sources in concrete productions is important, due to its Economical and environmental considerations. Pozzolans are one of these resources which decrease the environmental pollutions and production costs of concrete structures. Zeolite is an additive to cement clinker that if added to the high quality cement and concrete, it can be effective in enhancing the quality of cement and concrete resulting from high quality controlled precision and repeated sampling and continuous testing. Concrete creates the cement-free concrete without any additives. Documentary reports and rigorous scientific studies have shown that good pozzolan can, in addition to increasing the chemical resistance of concrete, eliminate the defects caused by the use of conventional cement in concrete and due to the diversity of water and soil use in different areas. In this study, the effect of Zeolite in different grades of cement on the mechanical properties and permeability of concrete at 7 and 28 days of age is investigated. It was found that with increasing cement grade, the water absorption rate of concrete increased. Also, the effect of Zeolite on the permeability of concrete samples is increased by increasing the pozzolan water absorption rate. Also, the effect of cement grade on the compressive strength of concrete was found to decrease with increasing concrete grade.

How to cite this article: Pirmohammadi Alishah F. The Effect of Zeolite on Different Mechanical Properties and Permeability of Self-Compacting Concrete. Comput Eng Phys Model 2020;3(1):53–68. https://doi.org/10.22115/cepm.2020.214817.1079

1. Introduction

The high level of waste production in the industrial processes as well as releasing pollutant gases, such as carbon dioxide in the cement production, has destructive effects on the environment and the quality of human life. One of the challenges of the recent decades is the production of concrete with lower clinker content but with similar mechanical and durability properties [1]. Numerous studies have been conducted with the aim of using wastes as cement replacement materials [2]. Different strategies such as reducing the water to cement ratio, thermal curing and use of mineral admixtures have been proposed to improve the properties of ultra-high performance concrete [3,4]. Among them, use of mineral admixtures appears to be the most effective and economical method owing to reducing the amount of cement consumption [5].

Today, concrete is one of the most widely used building materials in the world. This is due to its high strength, good performance and flexibility and its relatively low cost [6]. All of these features make concrete the focus of the construction and engineering community. For this reason, the strengths of concrete should be strengthened [7]. Pozzolies such as silica soot, rice husk ash, slag blast furnace, cane stem ash, zeolite, and fly ash have been found to be among the materials that improve concrete properties [8]. In this paper, we have attempted to explain the efforts to investigate the increase or decrease of concrete strength and permeability after the addition of Zeolite. When concrete is exposed to aggressive environments (for example, when exposed to sulfates and carbonates), it becomes corrosive due to its permeability. Resistance to sulfate and carbonate attacks can therefore be increased by reducing permeability [9].

Concrete is now undergoing remarkable developments over a period of more than five years since the emergence of Portland cement. The availability of its materials, its relatively high durability and the need for extensive construction of concrete structures such as buildings, structures, dams, bridges, tunnels and roads have made this material very popular [10]. Durability and strength of concrete structures in particular Due to the high volume of traffic and exposure to environmental factors in road-related structures such as bridge or marine bases, it has attracted much attention in the science of concrete technology [11]. Many efforts have been made to improve the strength and durability of concrete by the use of additives. The use of pozzolanic materials is one of the strategies to improve the strength and durability of concrete. The pozzolanic reactions fill the cavities in the concrete and reduce the porosity and permeability, thereby increasing the durability and strength of the concrete [12]. In making samples of different grades of cement 320, 340, 360, 380 and 400 as well as different percentages of Zeolite 2% - 6% - 8% - 12% - 15% was added to the cement.

In this study, by examining the effects of Zeolite on the concrete properties, the optimal percentage of Zeolite in the mixing scheme and its effect on the concrete properties were compared and presented in graphs and tables.

2. Lab program

2.1.Consumables

2.1.1. Aggregates

The stone material used in this project consists of three sections: sand, pea gravel and almond sand. The mace is up to 8 mm in size from the mines around Shabestar. Grading Table 1 shows the results of the grading test for the sand sample. The sand softness modulus was set at 3.99, which is, by comparison, common in the country's sand, compared to the range of grading mentioned by references such as ASTM C33 [13]. Pea sand grading has been selected to be within the range of grading as recommended by the authoritative authorities as far as possible.

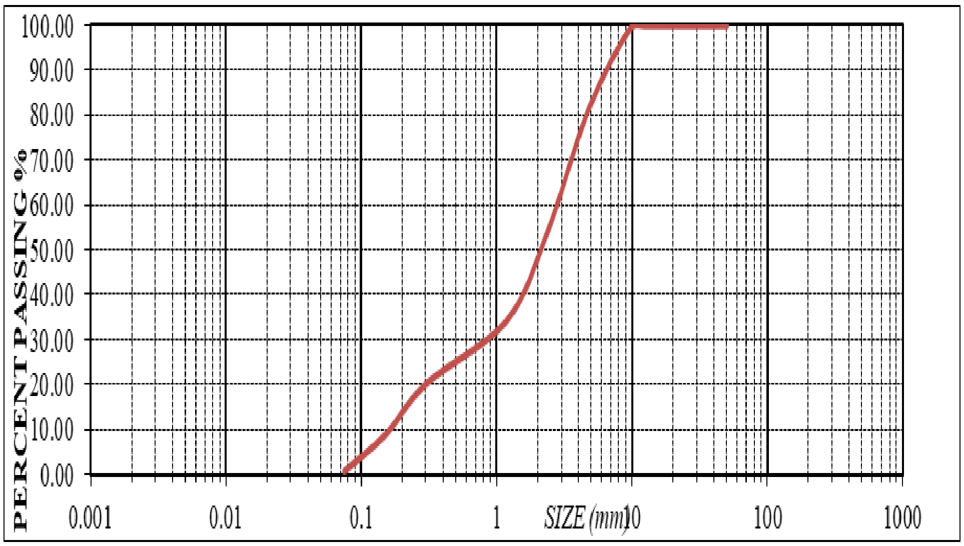

Fig. 1. Report of sand grading experiment.

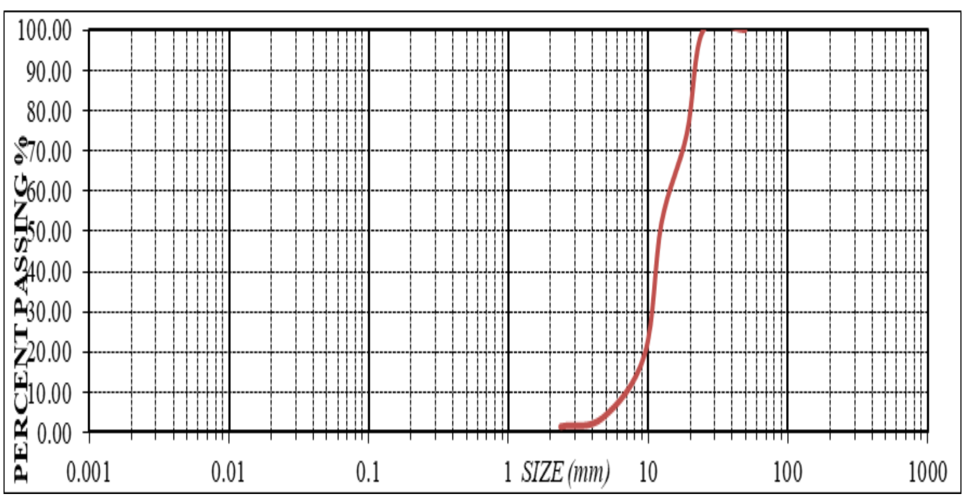

Fig. 2. Report of the pea sand aggregation experiment.

2.1.2. Cement

In this research, concrete type 2 Sufian cement with a softness of 2974 cm^2 was used to make concrete samples [14].

Table 1
Results of Sufian Type 2 Cement Mechanical Experiments.

Specific gravity gr/cm^3	3.11
Specific surface area gr / cm^2	2974
7-day compressive strength with standard sand (237 kg / cm^2)	237
28-day compressive strength with standard sand (kg / cm^2)	462
Initial Reception Time (minutes)	116
Final Reception Time (minutes)	175

Table 2
Chemical composition of cement used.

Chemical composition	(%)
CaO	63.13
SiO_2	21.77
Al_2O_3	4.53
Fe_2O_3	3.66
MgO	2.17
SO_3	2.22
Na_2O	0.32
K_2O	0.83

As the results show, the chemical composition and physical-mechanical properties of the cement used are in accordance with ASTM C125 standard requirements for Type 2 cement [15].

2.1.3. Water

The quality of water in concrete is important because impurities in it may affect the cement retention and cause disturbances. Inappropriate water may also have an adverse effect on concrete strength and may cause stains on the concrete surface and even rust on the reinforcement. In most mixtures, water is suitable for aqueous concrete, which is suitable for drinking. However, a potable water may not be suitable for concrete because of the high percentage of sodium and potassium ions present, which is associated with the risk of alkali reaction of rock particles. As a general rule, any water that has a pH (acidity) of between 2 and 3 and has no salinity taste can be used for concrete. Dark and odorous colors do not necessarily prove the existence of harmful substances in water.

In the process of concrete preparation, water is the main factor in the cement hydration and directly affects the cement retention time and the strength of the concrete.The water used in the preparation of concrete mixes for this project was drinking water in Tabriz [16].

2.1.4. Zeolite

The pozzolan used in this study (Zeolite) was a light green watermelon pozzolan from a light group that is well-watered.The following is the physical and chemical properties of Zeolite. The Zeolite mine of the Abike Cement Plant, one kilometer northeast of Abike, is the subject of this article. The area is geologically part of central Alborz and is affected by the Alborz orogenic phases. The exploitable materials of the mine are volcanic-sedimentary rocks of Karaj Formation with Eocene age which in these places are in layers with gentle slope to the south west [9].

Table 3
Physical and Chemical Properties of (Zeolite).

Chemical Compounds (%)	Zeolite Abic
SiO_2	64.45
Al_2O_3	13.39
Fe_2O_3	3.89
CaO	3.59
SO_3	1.83
MgO	1.10
Na_2O	1
K_2O	1.67
LOI	4.06
Specific weight (gr / cm^2)	2.55
Blain (gr / cm^2)	3400

2.2. The laboratory steps performed in this paper are step by step

- Wash sand (to remove silt and increase concrete strength) and dry by drying and flattening. -Weighting of materials based on percentages of mixing ratio.

- Mixing materials, lubricating molds and pouring concrete into molds for vibration.

- Smooth the surface of the molds, labeling and pasting in the right place.

- Remove the samples from the mold in the water tank After two days, the samples are removed from the mold and placed in a water tank at a temperature of +20 ° C.

It should be noted that the mixing of materials is such that a paste is obtained from one hand of concrete.

The specimens were broken by hydraulic jack at 7 and 28 days of age and their compressive strength was measured.

3. Calculate the mixing ratio

Concrete mix design is the process of determining the proportion of concrete components so that the concrete becomes as cost-effective as possible and meets the requirements including physical, mechanical and durability properties. The concrete mix design method will create a common language for those involved in the industry. Mix design is the process by which the proper composition of concrete components is determined according to the given technical specifications. The mix design mechanism is complex because changing a variable may affect the properties of the concrete in the opposite way. Therefore, the mixed design is the art of balancing these contrasting effects. However, in the mixed design other criteria such as reduction of creep, creep and so on may be considered.

The basics of the Iranian mixed design method are derived from the German method. The proposed method is considered as the national method of concrete mix design, in accordance with the standard of concrete aggregates (National Standard of Iran No. 302) as well as the Iranian Concrete Code and the Properties of Portland Cement (National Standard of Iran No. 389) [17].

To obtain the mixing ratio, first calculate the percentage of aggregate in one cubic meter of concrete, then calculate the volume of mold and the number of samples: Specific gravity of concrete is 2300 kg / m^3. In this study, the amount of Cement grade is 320-340-360-380-400 kg / m^3. It is known that the maximum nominal size of the aggregate mixture is 19 mm because more than 90% of it passes the 19 mm sieve. Therefore, due to the pumping of the concrete, it is attempted to have a grain curve between A19 and B19 and closer to B19. In this case, n appears to be 0.4 to 0.5. In the first place, the share of sand is 50%. It is observed that the resulting agglomeration is a bit coarse, so it seems to be 40% sand and 60% sand. However, if sand grading, especially in the case of particles smaller than 0.6 mm, was coarse, we might not be able to obtain proper grading. It should be said that the sand in Iran often loses its fine particles due to repeated and repeated washing, which will not solve the problem with increasing sand share.

By the way since the maximum actual size of the aggregate not 25 mm in the first sieve, 19 mm may not be a good match, which is reasonable. It should be noted that the sand share values can be between 45 and 40 and the sand share 55 to 60. For sand the resulting 45% and 55% sand blend seems a bit coarse, especially in the upper part. So the same share of sand is 40% and sand 60% more desirable.

The amount of free water in concrete depends on several factors such as desired performance, maximum aggregate size, aggregation and type of aggregates consumed in terms of texture and shape. Water content is the most important factor affecting concrete performance. Increasing the amount of water makes it easier to pour concrete and make it compressible. However, increasing water, in addition to decreasing resistance, results in the separation of particles and water drop.

The amount of water in the mixture should be sufficient to absorb the aggregate particles and then occupy the space between the aggregate particles to create a lubricating state by creating a layer of cement slurry on the aggregates. Therefore, smaller particles need more water. On the other hand, in the absence of fine particles (filler or filler), the concrete cannot be pasty, so the amount of water in the mixture cannot be considered independent of aggregate aggregation [18].

If more cement grade is used, it is necessary to increase the water content by about 1 to 2 kg / m3 of 10 cements per 10 kg. In cases where the lubricant or super-lubricant chemical is used in the concrete mixture, the water content of the mixture can be reduced by about 5 to 30%, without altering the amount of slip desired. The amount of water needed to bring the moisture content of the aggregates from dry to wet to saturated with dry surface should be adjusted to free water.

Also, the intentional air bubble in concrete generally reduces free water to provide efficiency. For each percent of intentional air bubbles (excess unwanted air), 2.5 percent of the free water required in the mixture is reduced.

After determining the amount of cement, it is necessary to correct the amount of water according to the previous step and to determine the amount of cement again. This correction is done only once and there is no need to repeat it.

The value of the cement calculated from the above formula shall be compared with the maximum or minimum stated in the specifications or durability requirements. If the value of the calculated cement is more or less than the desired value, that value must be selected. If cement substitute mineral additives (silica fume or fly ash) are used, the amount of water required and the cementitious material should be calculated taking into account the effective factor k [19].

Table 4
Component values of 320 kg / m^3 concrete mixes studied.

Slump	**Gravel (kg)**	**Sand (kg)**	**Zeolite (g)**	**Zeolite content**	**Cement (kg)**	**Water (kg)**	**W/C**	**Number**
11.5	6.121	9.21	-	-	2.544	1.33	0.5	1
12	6.121	9.21	50	2%	2.446	1.32	0.5	2
11	6.121	9.21	152	6%	2.538	1.26	0.5	3
10.5	6.121	9.21	199	8%	2.484	1.24	0.5	4
12	6.121	9.21	285	12%	2.376	1.18	0.5	5
12.5	6.121	9.21	382	15%	2.295	1.14	0.5	6

Table 5
Component values of 340 kg / m^3 concrete mixes studied.

Slump	**Gravel (kg)**	**Sand (kg)**	**Zeolite (g)**	**Zeolite content**	**Cement (kg)**	**Water (kg)**	**W/C**	**Number**
10.5	6.035	9.053	-	-	2.866	1.43	0.5	1
11	6.035	9.053	57.32	2%	2.808	1.4	0.5	2
12	6.035	9.053	171.96	6%	2.694	1.34	0.5	3
11.5	6.035	9.053	229.28	8%	2.636	1.31	0.5	4
11	6.035	9.053	343.92	12%	2.522	1.26	0.5	5
10.5	6.035	9.053	429.9	15%	2.436	1.21	0.5	6

Table 6
Component values of 360 kg / m^3 concrete mixes studied.

Slump	**Gravel (kg)**	**Sand (kg)**	**Zeolite (g)**	**Zeolite content**	**Cement (kg)**	**Water (kg)**	**W/C**	**Number**
10	5.934	8.902	-	-	3.034	1.54	0.5	1
12	5.934	8.902	60	2%	2.974	1.48	0.5	2
10	5.934	8.902	182	6%	2.851	1.42	0.5	3
10.5	5.934	8.902	242	8%	2.791	1.39	0.5	4
10	5.934	8.902	364	12%	2.669	1.33	0.5	5
9.5	5.934	8.902	455	15%	2.578	1.28	0.5	6

Table 7
Component values of 380 kg / m^3 concrete mixes studied.

Slump	Gravel (kg)	Sand (kg)	Zeolite (g)	Zeolite content	Cement (kg)	Water (kg)	W/C	Number
11	5.833	8.750	-	-	3.203	1.60	0.5	1
9	5.833	8.750	64.06	2%	3.138	1.56	0.5	2
10	5.833	8.750	192	6%	3.010	1.50	0.5	3
9.5	5.833	8.750	256.24	8%	2.946	1.47	0.5	4
10	5.833	8.750	384.36	12%	2.818	1.40	0.5	5
11.5	5.833	8.750	480.45	15%	2.722	1.36	0.5	6

Table 8
Component values of 400 kg / m^3 concrete mixes studied.

Slump	Gravel (kg)	Sand (kg)	Zeolite (g)	Zeolite content	Cement (kg)	Water (kg)	W/C	Number
9.5	5.732	8.598	-	-	3.372	1.68	0.5	1
11	5.732	8.598	67	2%	3.30	1.65	0.5	2
10	5.732	8.598	202	6%	3.169	1.58	0.5	3
10.5	5.732	8.598	269	8%	3.102	1.56	0.5	4
9	5.732	8.598	404	12%	2.967	1.48	0.5	5
8.5	5.732	8.598	505	15%	2.866	1.43	0.5	6

4. Results

After the laboratory steps (mixing ratios - preparation of materials - making samples.

-breaking samples and obtaining compressive strength) the above results are presented in the following diagrams.

The compressive strength of the specimens is written in two quantities:

- Quantity F which represents the force recorded in the concrete crushing machine

- The fc value, which represents the compressive strength in kg / cm^2 and is obtained by dividing the force by the sample area. For example, for example with the composition of micro silica we have:

F = 59470 kgf

A = 15 * 15 = 225 cm^2

fc = 59470/225 = 264.3 kg / cm^2

4.1. Effect of zeolite concrete treatment with 400 grade cement

In the study of the processing of concrete with Zeolite in 400 grade cement, it is shown in Figure 3 that with increasing of Zeolite percentage at early age (7 days) the amount of compressive strength decreases so that in 15% Zeoloite cement replacement. The control sample decreased the compressive strength by 9%.

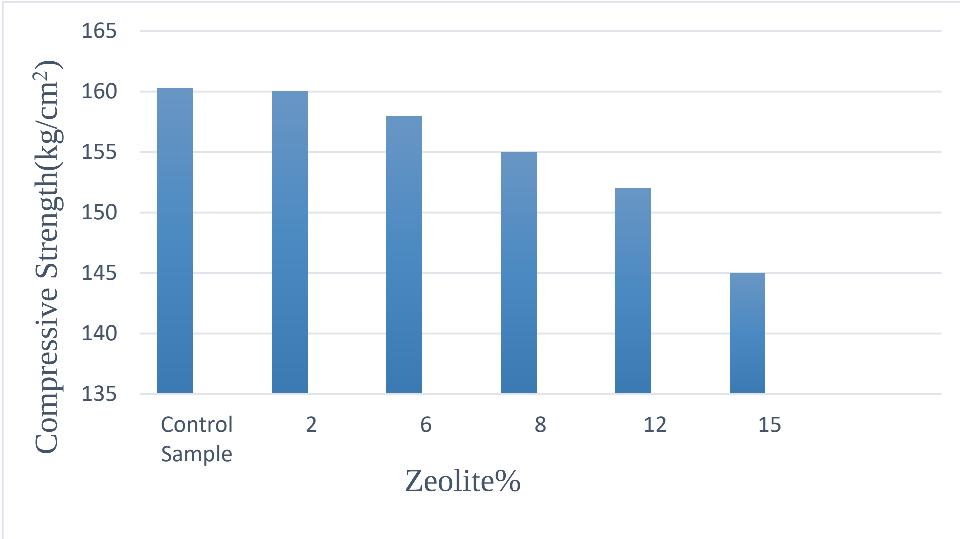

Fig. 3. Concrete strength with different percentages of Zeolite with 400 grade cement at 7 days old concrete.

Further, in the study of cementitious application of Zeolite to 400 grade cement at 28 days of age, it was found that up to 8% increased with increasing Zeolite 2% resistance, but in 12 and 15% samples, Zeolite replaced cement.

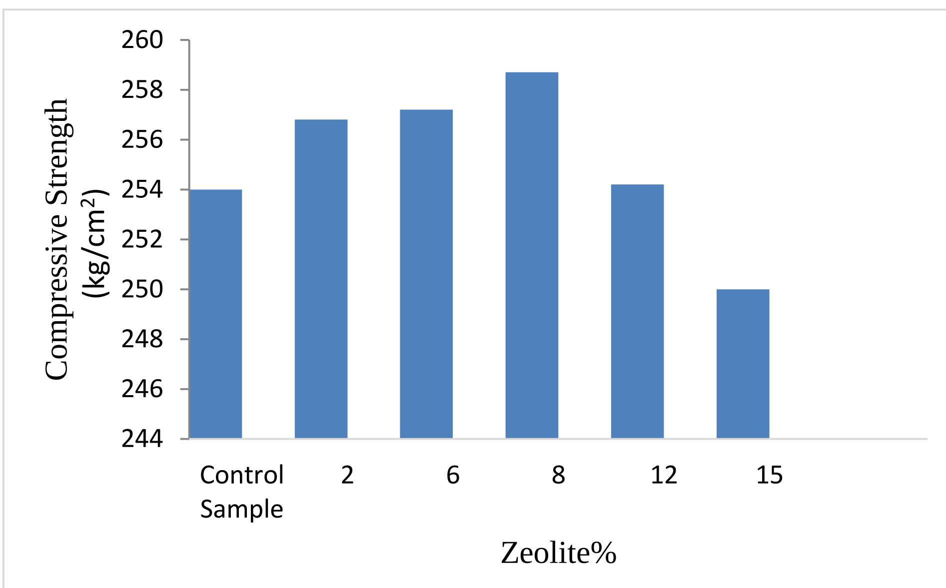

Fig. 4. Concrete strength with different percentages of Zeolite with 400 grade cement at 28 days old concrete.

4.2. Effect of zeolite concrete treatment with 380 degree cement

In the study of the processing of concrete with Zeolite in 380 grade cement it was observed that in Fig 5 the percentage of compressive strength decreases with increasing of Zeolite at early age

(7 days), so that in 15% of Zeolite cement replacement compared to cement. The control sample decreased compressive strength by 7%.

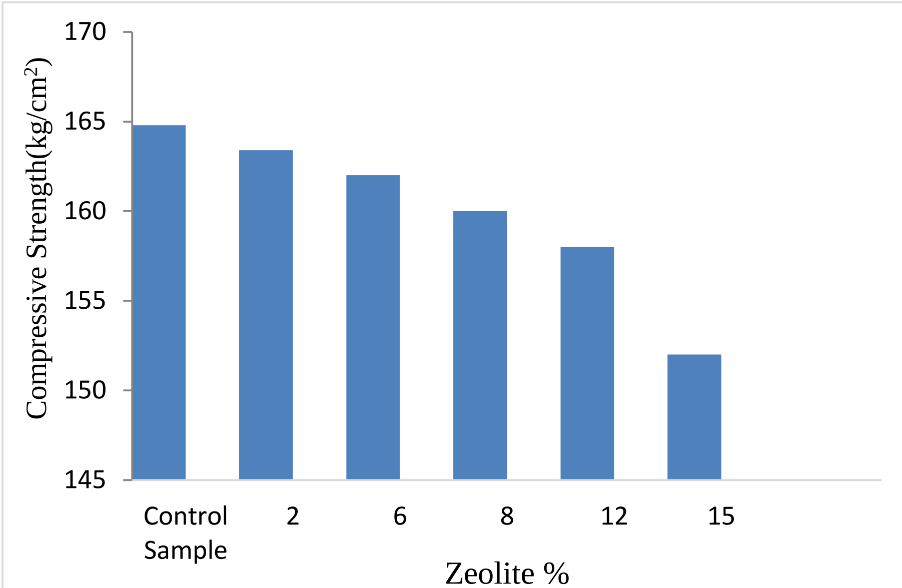

Fig. 5. Concrete strength with different percentages of Zeolite with 380 grade cement at 7 days old concrete.

Further, in the study of cementitious treatment with Zeolite in 380 grade cement at 28 days of age it was observed that up to 8% increased with increasing Zeolite 2.5% resistance but in 12 and 15% samples, Zeolite replaced cement. Compared to the control sample, it decreased.

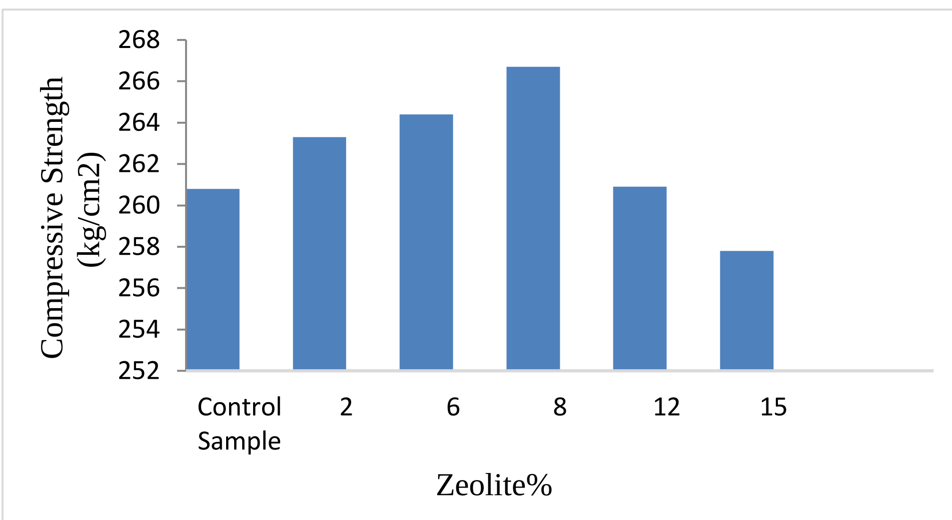

Fig. 6. Concrete strength with different percentages of Zeolite with 380 grade cement at 28 days old concrete.

4.3. Effect of zeolite concrete treatment with 360 degree cement

In the study of cementitious treatment with Zeolite in 360 grade cement, it is shown in Fig. 7 that with increasing the percentage of Zeolite at an early age (7 days), the amount of compressive strength decreases as compared to 15% Zeolite cement replacement. The control sample decreased the compressive strength by 6%.

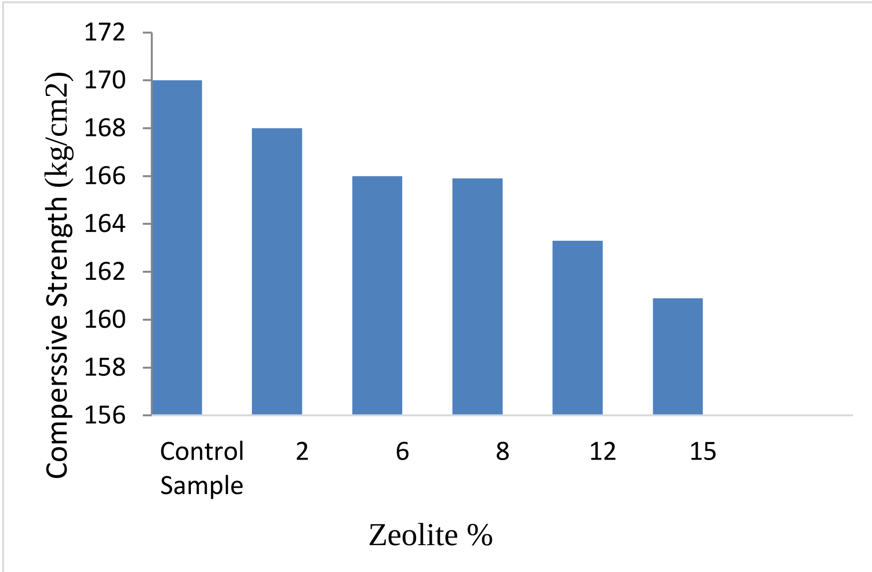

Fig. 7. Concrete strength with different percentages of Zeolite with 360 grade cement at the age of 7 days of concrete.

Further, in the study of cementitious treatment of Zeolite with 360 grade cement at 28 days of age, it was found that up to 8% increased with increasing Zeolite 3% resistance, but in 12 and 15% samples, Zeolite replaced cement. The control sample has decreased.

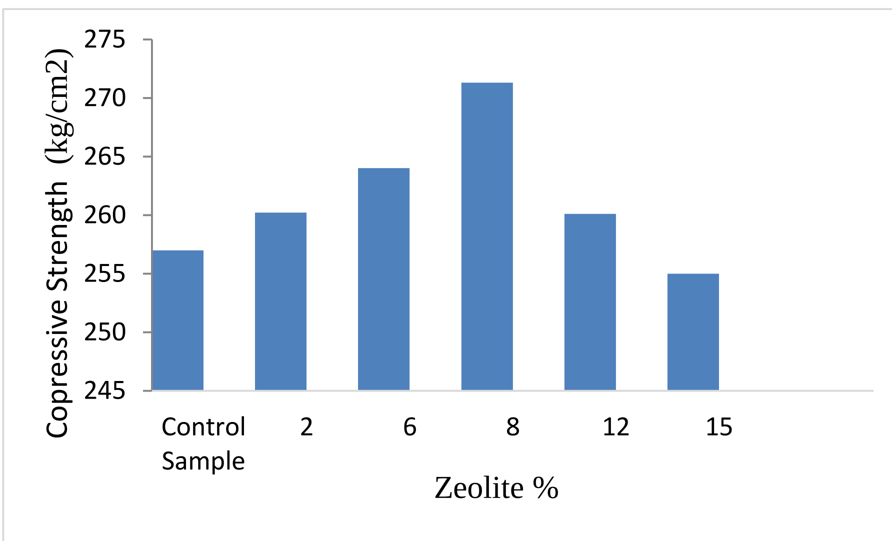

Fig. 8: Concrete strength with different percentages of Zeolite with 360 grade cement at 28 days of age

4.4. Effect of zeolite concrete treatment with 340 degree cement

In the study of the processing of concrete with Zeolite in 340 grade cement, it was observed that in Fig. 9 the compressive strength decreases with increasing of Zeolite at early age (7 days), so that in 15% of Zeolite cement replacement compared to cement. The control sample had a compressive strength of 5.8%.

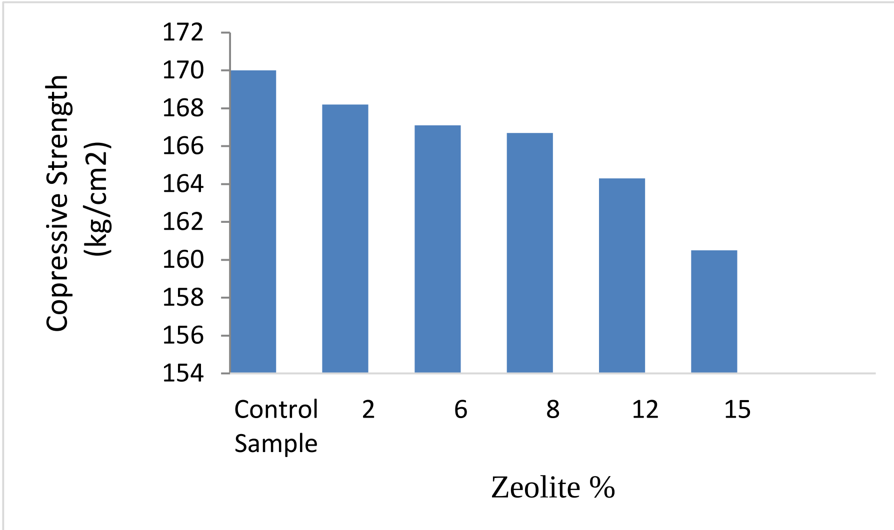

Fig. 9. Concrete strength with different percentages of Zeolite with 340 grade cement at 7 days old concrete.

Further, in the study of cementitious treatment with Zeolite in 340 grade cement was observed at 28 days of age, which increased by almost 8% with increasing Zeolite 3.5% resistance, but in 12 and 15% samples, substitute cement was observed. Resistance to the control sample decreased.

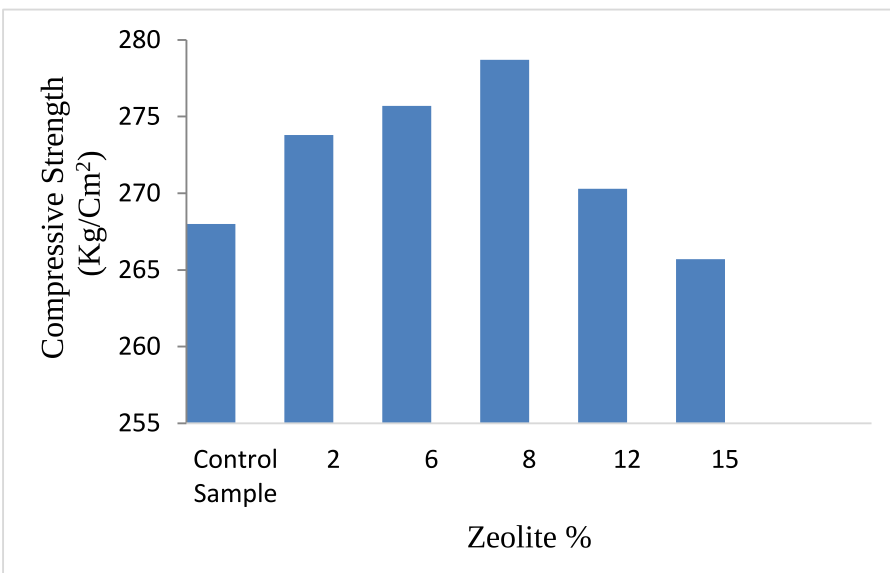

Fig. 10. Concrete strength with different percentages of Zeolite with 340 grade cement at 28 days old concrete.

4.4. Effect of zeolite concrete treatment with 320 degree cement

In the study of cementitious treatment with Zeolite in 320-grade cement, it was observed that in Fig. 11, the increase in the percentage of Zeolite at an early age (7 days) reduced the amount of compressive strength to 15% of cement substituted pozzolan. The control sample had a compressive strength of 5.7%.

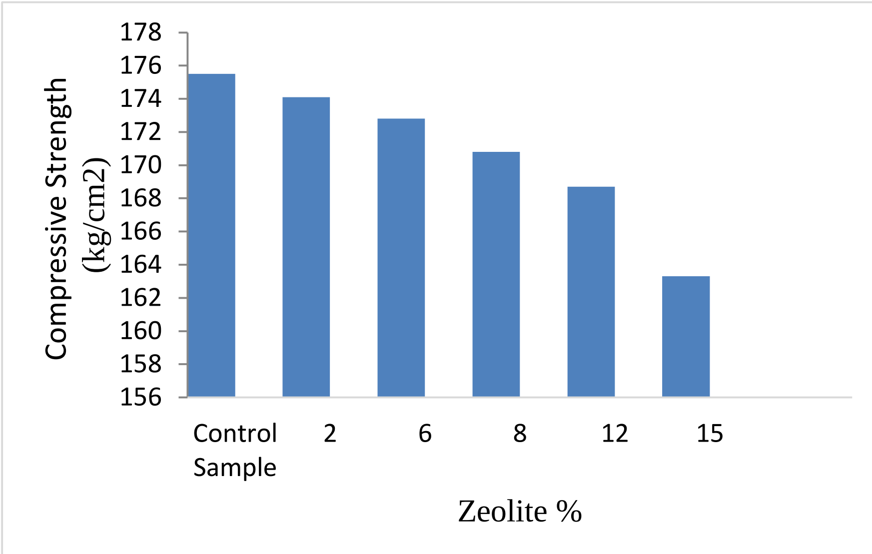

Fig. 11. Concrete strength with different percentages of Zeolite with 320 grade cement at the age of 7 days of concrete.

Further, in the study of cementitious treatment with Zeolite in 320 grade cement at 28 days of age, it was observed that up to 8% increased with increasing Zeolite 4% resistance, but in 12 and 15% samples, Zeolite cement replacement was observed. The control sample decreased.

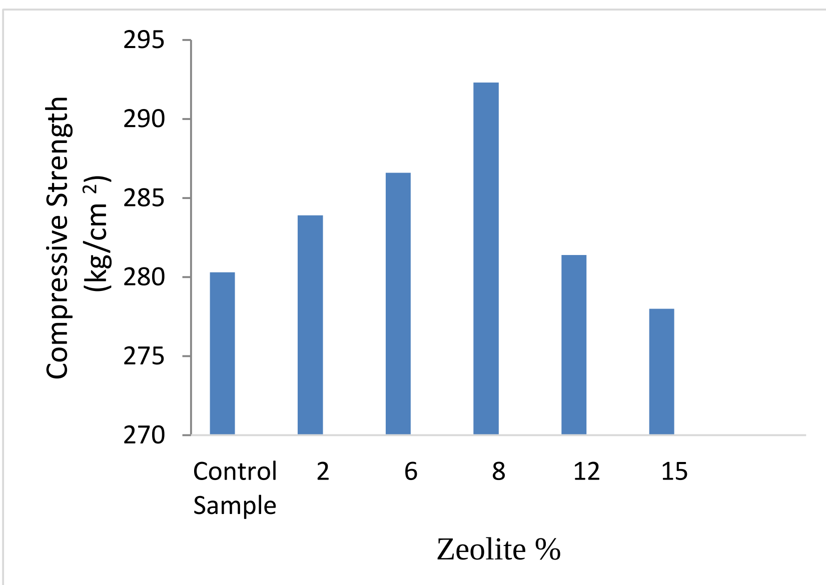

Fig. 12. Concrete strength with different percentages of Zeolite with 320 grade cement at 28 days of concrete.

4.5. Water absorption percentage

The water absorption test was performed in accordance with BS 1881-Part 122 [20]. The test method is that at 28 days of age, each of the concrete samples, with different percentages of pozzolan, were dried in the incubator at a temperature of approximately 45 ° C for 5 days. After the samples were removed from the incubator, the samples were weighed in a dry state and then placed in a water container.

This was done so that the water height above the specimens was 25 + 5 mm. The specimens were left in water for 24 h and then extracted and weighed in saturation with dry surface.

The results show that with increasing cement grade, the water absorption rate of concrete increases. Also, the effect of Zeolite on the concrete samples can be observed by increasing the amount of water absorbed by Zeolite.

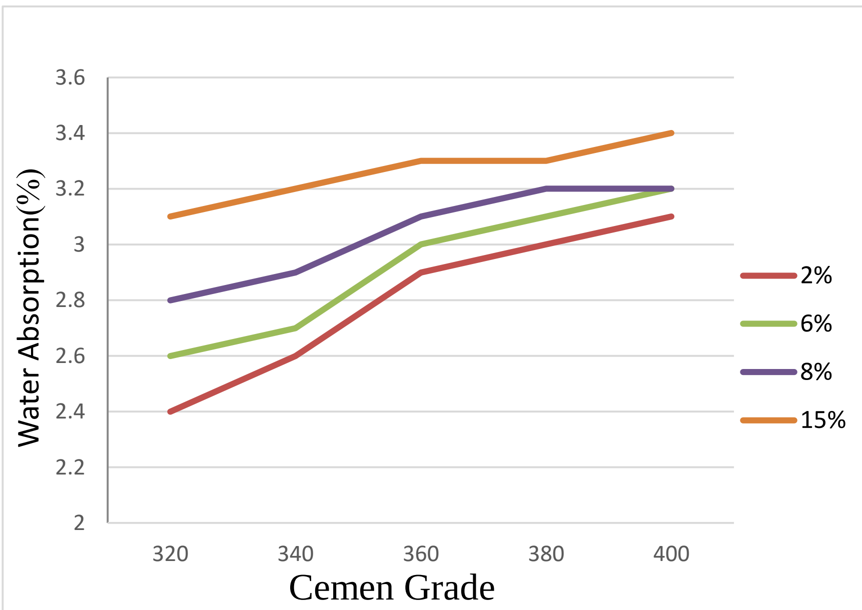

Fig. 13. Diagram of water absorption percentage of concrete containing abiotic Zeolite to cement grade.

5. Conclusion

The results of this study indicate that with increasing percentage of Zeolite replacement at low ages the compressive strength of concrete decreases but at higher ages with increasing percentage of Zeolite replacement the compressive strength increases. This increase persists to 8% of Zeolite, but decreases thereafter. These results are detailed below:

1. In the study of processing of Zeolite concrete in 400 grade cement it was observed that increasing the percentage of Zeolite at early age (7 days) decreases the amount of compressive strength. Compressive strength of 9% was decreased in 15% of Zeolite replacement cement compared to the control sample. Concrete Concrete processing with Zeolite was observed in 400 grade cement at 28 days of age, which increased by almost 8% with increasing Zeolite 2%

resistance. However, in 12 and 15% of Zeolite cement replacement samples, resistance to control was reduced.

2. In the study of processing of Zeolite concrete in 380 grade cement, compressive strength decreases with increasing percentage of Zeolite at early age (7 days). In 15% of Zeolite replacement cement, the compressive strength decreased by 7% compared to the control. Concrete processing with Zeolite was observed in 380 grade cement at 28 days of age, which increased by almost 8% with increasing Zeolite 2.5%. However, in 12 and 15% of Zeolite cement replacement samples, resistance to control was reduced.

3. In the study of the processing of concrete with Zeolite in 360 degree cement, it was observed that by increasing the percentage of Zeolite at an early age (7 days), the amount of compressive strength decreased. In 15% of Zeolite cement replacement, the compressive strength decreased by 6% compared to the control sample. Concrete processing with Zeolite was observed in 360 degree cement at 28 days of age, which increased by almost 8% with increasing Zeolite 3% resistance. However, in the 12 and 15% samples of Zeolite, cement replacement was observed, which decreased with respect to the control sample.

4. Concrete processing with Zeolite and cement with 340 grade cement was observed by increasing the percentage of Zeolite at an early age (7 days) the amount of compressive strength decreased, with 5.8% decrease in compressive strength of 15% Zeolite as compared to the control sample. The study of the processing of concrete with Zeolite and cement with 340 grade at 28 days of age showed that almost 8% increased with increasing Zeolite 5.3% resistance. However, in 12 and 15% of Zeolite cement replacement samples, resistance to control was decreased.

5. Concrete processing with Zeolite in 320-degree cement transplanting decreases compressive strength by increasing the percentage of Zeolite at an early age (7 days). In 15% of Zeolite cement replacement, compression strength decreased by 7.5%. Concrete processing with Zeolite and cement with 320 grade C at 28 days of age showed that almost 8% increased with increasing Zeolite 4% resistance, but in 12 and 15% cozy substituted cementitious samples, resistance to control sample was observed. Has been reduced.

6.The results show that with increasing cement grade, the water absorption rate of concrete increases.

7. Investigation of the effect of Zeolite on concrete specimens is observed with increasing Zeolite water absorption rate.

8. Compressive strength analysis showed that increased Zeolite reduced concrete strength.The effect of cement grade on the compressive strength of concrete was found to decrease with increasing grade of concrete.

References

[1] Rangaraju PR, Olek J, Diamond S. An investigation into the influence of inter-aggregate spacing and the extent of the ITZ on properties of Portland cement concretes. Cem Concr Res

2010;40:1601–8. doi:10.1016/j.cemconres.2010.07.002.

[2] Moura WA, Gonçalves JP, Lima MBL. Copper slag waste as a supplementary cementing material to concrete. J Mater Sci 2007;42:2226–30. doi:10.1007/s10853-006-0997-4.

[3] Wang XH, Jacobsen S, Lee SF, He JY, Zhang ZL. Effect of silica fume, steel fiber and ITZ on the strength and fracture behavior of mortar. Mater Struct 2010;43:125.

[4] Wu Z, Shi C, Khayat KH. Influence of silica fume content on microstructure development and bond to steel fiber in ultra-high strength cement-based materials (UHSC). Cem Concr Compos 2016;71:97–109. doi:10.1016/j.cemconcomp.2016.05.005.

[5] Modarres A, Hesami S, Soltaninejad M, Madani H. Application of coal waste in sustainable roller compacted concrete pavement-environmental and technical assessment. Int J Pavement Eng 2018;19:748–61. doi:10.1080/10298436.2016.1205747.

[6] Parhizkar T, Najimi M, Pourkhorshidi AR, Jafarpour F, Hillemeier B, Herr R. Proposing a new approach for qualification of natural pozzolans 2010.

[7] Ichikawa T. Alkali–silica reaction, pessimum effects and pozzolanic effect. Cem Concr Res 2009;39:716–26. doi:10.1016/j.cemconres.2009.06.004.

[8] Bondar D, Lynsdale CJ, Milestone NB, Hassani N, Ramezanianpour AA. Effect of type, form, and dosage of activators on strength of alkali-activated natural pozzolans. Cem Concr Compos 2011;33:251–60. doi:10.1016/j.cemconcomp.2010.10.021.

[9] Tanyildizi H. Variance analysis of crack characteristics of structural lightweight concrete containing silica fume exposed to high temperature. Constr Build Mater 2013;47:1154–9. doi:10.1016/j.conbuildmat.2013.05.060.

[10] Song H-W, Pack S-W, Nam S-H, Jang J-C, Saraswathy V. Estimation of the permeability of silica fume cement concrete. Constr Build Mater 2010;24:315–21. doi:10.1016/j.conbuildmat.2009.08.033.

[11] Jahangir H, Bagheri M, Delaware S. Estimating Compressive Strength of Concrete by Swapping Pinion Ash for Cement. J Struct Constr Eng 2018;5:5–19.

[12] Ahmadi B, Shekarchi M. Use of natural zeolite as a supplementary cementitious material. Cem Concr Compos 2010;32:134–41. doi:10.1016/j.cemconcomp.2009.10.006.

[13] Valipour M, Pargar F, Shekarchi M, Khani S. Comparing a natural pozzolan, zeolite, to metakaolin and silica fume in terms of their effect on the durability characteristics of concrete: A laboratory study. Constr Build Mater 2013;41:879–88. doi:10.1016/j.conbuildmat.2012.11.054.

[14] ASTM. Standard terminology relating to concrete and concrete aggregates 2012.

[15] National Iranian Standard No. 1- 12284: Concrete - Part 1- Technical Specification Guide, 2009 n.d.

[16] Dhir RK, McCarthy MJ, Zhou S, Tittle PAJ. Role of cement content in specifications for concrete durability: cement type influences. Proc Inst Civ Eng - Struct Build 2004;157:113–27. doi:10.1680/stbu.2004.157.2.113.

[17] Poon CS, Lam CS. The effect of aggregate-to-cement ratio and types of aggregates on the properties of pre-cast concrete blocks. Cem Concr Compos 2008;30:283–9. doi:10.1016/j.cemconcomp.2007.10.005.

[18] Shi C. Effect of mixing proportions of concrete on its electrical conductivity and the rapid chloride permeability test (ASTM C1202 or ASSHTO T277) results. Cem Concr Res 2004;34:537–45. doi:10.1016/j.cemconres.2003.09.007.

[19] ACI 237R-07, “Self-Consolidating Concrete”, American Concrete Institute, 2007.

[20] BS 1881- Part 122;"Method for Determination of Water Absorption", British Standard, 1983.