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Investigation of the Pumice Additive Effect in Azarshahr Region on Mechanical Properties and Self-compacting Concrete Performance

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ABSTRACT

This paper presents the development of self-compacting lightweight concrete (SCLC) incorporating pumice. Seven concrete series with water–binder ratios of 0.4 and a constant total binder content of 550 kg/m^3 were designed. The pumice was added at proportions corresponding to 5%, 10%, 15%, 20%, 25% and 30% by weight of cement. The performance of mixtures was evaluated by conducting comprehensive series of tests on fresh and hardened properties. Fresh properties of mixtures were assessed by slump flow diameter, T_{50}, V-funnel flow time and L-Box. Also hardened properties were investigated via compressive strength, flexural strength, density and water absorption. The fresh concrete test results revealed that by substituting optimum levels of pumice in SCLC, satisfactory workability and rheological properties can be achieved. 10% pumice significantly enhanced the compressive and flexural strength of SCLC at later ages. The density of the SCLC containing pumice was lower than those of the control SCLC. A lower absorption and permeability can be achieved for mixes especially mixtures incorporating 10% pumice. In general, it seems that 10% pumice can be considered as a suitable replacement regarding to the economic efficiency, fresh and hardened properties. Petrographic examination of concrete samples shows that pumice aggregates are in the range of basalt to basalt andesite and have about 30% porosity. The minerals inside the pumice aggregates include feldspar and hornblende and some quartz, as well as some fine iron oxide minerals.

1. Introduction

Self-compacting concrete is a new phenomenon in the science of building materials that is less than two decades old and has provided new facilities that can be used to solve problems caused by improper compaction in the structure. Concrete includes reducing the life and durability of structures and increasing the quality and durability of concrete. It is almost impossible to replace concrete with other materials due to its various applications. On the other hand, paying attention to concrete is inseparable from paying attention to its constituents. The performance and properties of concrete largely depend on the amount and dimensions of the microstructures used in it. Particles on the nanoscale have different and unique physical and

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chemical properties. Therefore, it seems that the use of cement-based nanomaterials leads to the production of concrete with high strength properties and very low permeability. Today, to achieve greater strength and reliability, in addition to the main constituents of concrete, namely water, cement, and aggregates, other materials are used in concrete called pozzolanic materials. These materials can be mentioned as the fourth factor in concrete production. In addition, pozzolanic materials provide durability and quality of concrete in different conditions. Successful use of these materials depends to a large extent on the richness of technical knowledge related to their use during execution and post-execution maintenance (Azarafza et al., 2017).

In recent years, the use of natural pozzolans in self-compacting concrete has been considered by researchers both because of their effective role as fillers in the properties of fresh concrete and the effects on the mechanical properties of this concrete. One of these natural pozzolans studied in this study was pumice, which was used to study the fresh and hardened properties of self-compacting concrete. Igneous materials such as pumice, which have an unchanged glass and alumina structure and are porous textures, are among the natural pozzolanic materials. In Iran, there are significant sources of these substances in the Taftan region in Sistan and Baluchestan province, in the Sabalan region, and in the Damavand region in the north of Tehran. Due to the importance of recognizing the issues related to the use of this additive in concrete and familiarity with the correct methods of use and its positive and negative characteristics, it is necessary to conduct basic research in this field, because knowing this material makes it possible to use it optimally to improve the quality and durability of concrete (Corinal and Moriconi, 2003).

Self-compacting concrete (SCC) has been introduced as a breakthrough in concrete manufacturing in the last decade. Although at the beginning of the development of this concrete, the specialized labor force was very scarce for it which proved to have many economic advantages. Initially, the technology of making self-compacting concrete was developed in Japan, and it was possible to build it with the growth and development of superplasticizers quickly. Self-compacting concrete is now popular throughout Europe and is widely used in both construction and prefabricated parts. The Japanese have used it in the construction of bridges, tunnels, and buildings since 1990, after self-compacting concrete, which did not require any vibration and reached full density (Skarendahl and Peterson, 2000). Self-compacting concrete is defined in such a way that it does not need any internal or external vibrations and compresses itself with its weight. When it flows into the mold, it is completely aerated and fills the mold only by using the gravitational force and covers the existing reinforcements and at the same time maintains its uniformity (Mallah, 2005).

Self-compacting concrete in different parts of the structure with a percentage of reinforcement fills all the gaps and gaps, flows like honey and after pouring the concrete, has a surface close to the horizon. Depending on its composition, this concrete contains the same commonly vibrated compounds such as cement, aggregates, water, and additives that can be vibrated without any effort to ensure complete filling of the formwork, even when due to the short distance between the reinforcements, it is not possible to reach, it falls under its weight and becomes compacted (Frank, 2000).

It should be noted that in self-compacting concrete to achieve sufficient density and fill the space between the reinforcements, fresh concrete must have both high fluidity and good adhesion at the same time because high fluidity alone is not enough. When the concrete does not have high adhesion, when the concrete flows near a barrier, the coarse aggregates may be stopped by the barrier and start cutting the concrete mortar and stop the flow of concrete (BE 963801, 2000). In 1975 and 1976, some concretes that met these conditions were studied. At that time, none of the modern materials based on superplasticizers and viscosity modifiers were available. However, the simultaneous use of melamine or naphthalene with a high percentage of fine-grained materials proved that it can be effective in improving viscosity and mental health (Corinal and Moriconi, 2003).

The use of self-compacting concrete is expanding globally due to its properties in fresh and hardened concrete (Frank, 2000). Self-compacting concrete materials are often more expensive than conventional concrete, but increasing costs will improve production, shorten construction time, and improve working conditions. In Japan, Holschemacher and Vette Klug (2002) has used for the most optimal use of self-compacting in high-rise buildings, as well as for advanced tunnels in combination with steel fibers (Persson, 1998a,b). Also in Sweden, an increase in productivity of up to 60% has been observed due to the use of self-compacting concrete on highway bridges (Persson, 1999a). The use of this concrete, especially in cases of underwater concreting, has been reported in a desirable way (Persson, 1999b).

In recent years, the use of natural pozzolans in self-compacting concrete has been considered by researchers both because of their effective role as fillers in the properties of fresh concrete and the effects on the mechanical properties of this concrete. One of these natural pozzolans studied in this study was pumice, which was used to study the fresh and hardened properties of self-compacting concrete. Igneous materials such as pumice, which has an unchanged glassy structure and silicate alumina and porous texture, are among the natural pozzolanic materials. In Iran, there are significant sources of these substances in the Taftan region in Sistan and Baluchestan province, in the Sabalan region, and in the Damavand region in the north of Tehran. The first major use of this pozzolan was used in Jagin and Zirdan dams. The results of tests performed on Taftan pozzolan powder in ordinary concrete indicate its proper activity, which shows the best strength in the range of 15 to 25%

replacement with cement (Shaygi Nik, 2006). However, the results of Kelestemur and Demirel's research show that the use of natural pumice pozzolans reduces the compressive strength of concrete (Kelestemur and Demirel, 2010). The results of Hossain's research also show that the application of natural pumice of pumice at the age of 28 days reduces the compressive strength and by increasing the replacement rate of pumice up to 30%, the rate of reduction of compressive strength of concrete increases (Hossain, 2008). Ramezanianpour et al. (2011) studying the effects of pozzolanic materials on the durability of self-compacting concrete concluded that it is possible to use pumice as a pozzolan in self-compacting concrete and achieve such concrete with the desired quality, with the ability to meet the requirements of self-compacting concrete in terms of conditions Fresh concrete (such as the ability and speed of proper deformation, without separation and dewatering) is possible. According to Sarani et al. (2013) studies conducted by On the simultaneous use of pumice with zeolite powder as a substitute for cement used in self-compacting concrete, the amount of pumice replacement was 10% with simultaneous amounts of 0, 5, 10, and 15% zeolite Were used and they found that increasing the zeolite replacement reduced the slip flow of fresh concrete and reduced the compressive strength of 7 and 28 days.

2. Material and Methods

2.1. Implemented methodology

Experimental research is the formal and classical method of experiments and scientific and laboratory research, which, while difficult to implement, is one of the most accurate and powerful methods of discovering the truth and spreading knowledge. In this method, the researcher should be aware of the impact of other factors on the research results and control these unwanted factors and somehow eliminate their influence so that he can more conclusively and objectively, the desired results about the relationship between manipulation factors and their effects, are achieved. Therefore, the practical phase must be done with great care, as well as with careful planning and control of the situation, so that the effect of all effective factors can be considered in a completely accurate and controlled manner in the experiment. The experiments were performed in the laboratory of the Shabestar Branch of Azad University and Tabriz University.

Sand: Very fine clay and particles usually cover the surface of the grains and have a major effect on the adhesion and cohesion of the grains and cement paste. For this reason, in the present study, the sand used to remove clay particles was washed away. Because the type and amount of sand used in making mortar affect its mechanical properties, regulations have set strict standards for the sand used. Bad grains of sand used in mortar making according to ASTM C136-01 are given in Table 1. The apparent specific gravity in saturation with its dry surface was 2.65 and its water absorption percentage was 1.2.

Gravel: The Gravel used is broken stone. In the preparation of concrete, an attempt was made to avoid the use of stones in the shape of needles or flakes. Even though the sand used was free of soil and excess materials, to ensure more, the used sand was washed uniformly before the start of the tests and after washing, the necessary measures were taken to achieve the same moisture content for the experiments. The apparent specific gravity in saturation with its dry surface was 2.6 g/cm^3 and its water absorption percentage was 1.01.

Super lubricant: Lubricants produce very large water-soluble molecules called anions or negatively charged particles. These particles surround the particles in fresh mortar or concrete, especially cement grains, and suspend them, eventually absorbing the particles in mortar or concrete. The use of superplasticizers reduces the amount of water consumed while maintaining the efficiency of mortar or concrete. In theory, the ratio of water to cement required for the hydration phenomenon is 18%, which decreases with increasing the compressive strength of concrete. With the proper use of lubricants at normal temperatures with the right amount of aggregate and cement, the amount of water in the mixture may be reduced by up to 33%. On the other hand, the use of superplasticizers also increases the durability and short-term resistance, and Ethan acquires waterproof properties, which in turn saves work time, manpower, and machinery and materials. In this research, Vand Superplast PCE superplasticizer has been used, which is a new generation of superplasticizers.

Cement: Choosing the right type of cement is very important in concrete production. If short-term strength is considered, the use of Portland cement type 3 is recommended. If cement is used in a large mix design that generates a lot of heat, it is better to use type 2 cement. The cement used in this research was Portland type 2 with a specific weight of 3150 kg/m^3 and the specific surface was 3250 cm/g by the Blaine method. It should be noted that the amount of Moore cement required for constant strength varies depending on the different types of grains used. In principle, the amount of cement for constant strength depends on the strength and modulus of deformation of the consumed grains. Care should be taken that the grade of cement is not less than 300 kg/m^3 (Iranmanesh and Hashemi, 2001).

Water quality: Water quality is important because the impurities in it may affect the setting of the cement and cause disturbances. By most standards, water suitable for mortar and concrete is water that is suitable for drinking. The water used in this project is drinking water of Sanandaj city.

Pumice: Pumice is consumed from mines located on the slopes of Sahand in Azarshahr with a specific density of 2.3 g/cm^2 which is shown in Fig 1. The chemical decomposition of pumice is given in the table below.

Figure 1. Pumice used in self-compacting concrete

Table 1. Sand granulation used in making samples

Sieves size	Pass percentage	ASTM requirements
4.75 mm	96	87 - 100
2.36 mm	82.4	74 - 98
1.18 mm	68.2	58 - 80
600 µm	42.5	38 - 60
300 µm	20.7	15 - 34
150 µm	6.9	2 - 12

Table 2. Chemical decomposition of used cement and pumice

No.	Chemical Composition	Pumice percents
1	SiO_2	55.20
2	Al_2O_3	20.75
3	Fe_2O_3	1.26
4	CaO	6.80
5	MgO	2.30
6	SO_3	0.44
7	K_2O	1.73
8	Na_2O	1.80
9	LOI	1.95

2.2. Preparing pumice seeds for use in concrete

For various experiments, the sample was transferred from Pokeh mine in Eskandan village of Azarshahr to the laboratory, and mineral and concrete technology laboratories were used to carry out the project. To use pumice in mortar and concrete, its particle size must be below 75 microns, which is larger than this particle size in the sample, so it must be used using crushing and grinding machines. Reach the desired size. For this purpose, the first 5 kg of the sample is crushed in a cylindrical crusher and then divided into 5 samples of 1 kg. In the next stage, a 1 kg sample is placed in a dry ball mill for 15 minutes, and the reason why the dry type is used is that in the next stage of the experiments, pumice will be used to make concrete. The results of the diagrams show that more than 50% of the particles from the dry bullet mill are smaller than 75 microns in size, so the target mill has worked well. The diameter of Asia used is 22 cm and its height is 25.5 cm. After several stages of dry ball milling for the desired pumice, the required amount of concrete was provided (Fig. 2).

2.3. Self-compacting concrete mixing plan

The selection of mixing materials and their ratios is called a mixing plan and the purpose of selecting mixing ratios is the process of selecting suitable composite materials for concrete or mortar and determining their relative amounts with the aim that the concrete or mortar produced is as economical as possible and has some One of the minimum required properties, especially resistance, is durability and mentality (Neville, 1999). It should be noted that design in the exact sense is not possible, because the materials are variable in different aspects and some of their properties cannot be quantitatively evaluated. Therefore, in order to achieve a satisfactory mixture, we must control the obtained ratios by making experimental mixtures and, if necessary, apply the required changes in the component ratios to achieve a satisfactory mixture. Self-compacting concrete has the same design as ordinary concrete, which includes aggregate, cement, water and additives. Of course, more superplasticizer is used to reduce the liquid limit of concrete and its better performance, as well as a large amount of filler as a fluid agent and easier movement of coarse grains. The fresh and hardened properties of self-compacting concrete are highly dependent on its mixing design (Frank, 2000). Understanding the basic principles of mixed design is more important than its computational work. Only when the principles of mix design are understood can the required quality be maintained by concrete production control methods throughout the work.

The mix design is just a means of producing concrete with all the desired properties from start to finish. Efficiency is a characteristic that determines the degree of ease with which, if acceptable materials are used, fresh concrete can be poured and polished without harmful separation (Neville, 1383). In this research, self-compacting concrete was designed with trial and error to meet the tests of fresh concrete. In the first stage, to obtain composite cement with superior strength properties, concrete samples with different percentages of pumice were made as a relative alternative to cement, and the compressive and flexural strength of the samples at different ages of 7, 3, and 28 days were evaluated. After reviewing the results, the optimal percentage of pumice replacement with cement was determined. In the second stage of experiments, to investigate the effect of pumice on the matrix, these aggregates were added to concrete in different percentages of cement weight and compressive and flexural strength, water absorption, and specific gravity at 28 and 90 days of age were investigated.

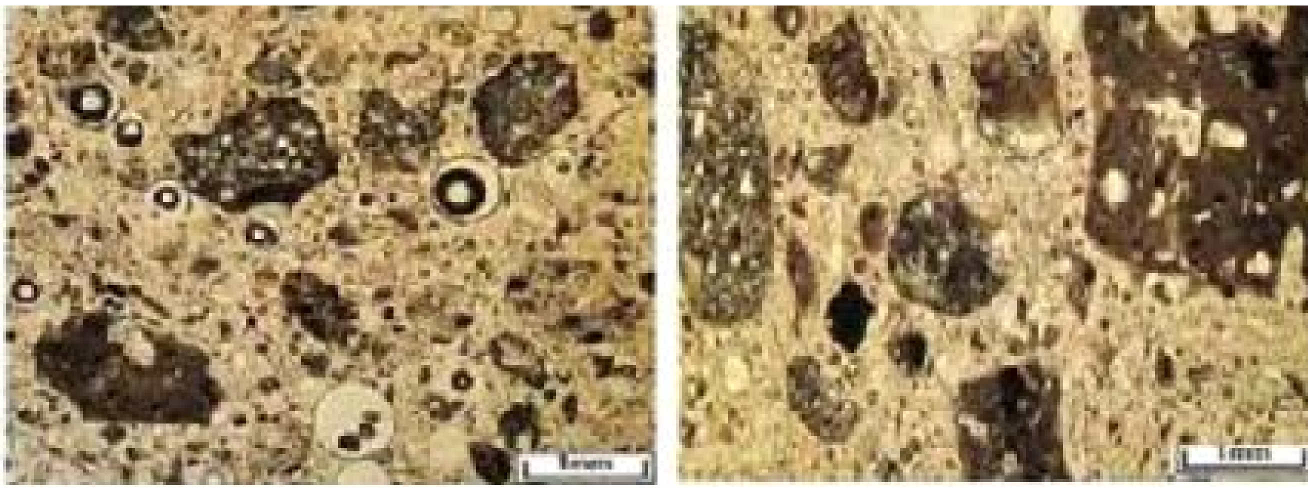

Figure 2. Microscopic images show pumice of the target area, which has a hollow and lytic texture

Table 3. Sample mixing scheme

Mixed	Cement (%)	Pumice (%)	Cement (kg/m^3)	Water (kg/m^3)	Pumice (kg/m^3)	Mixed Sand (kg/m^3)	Sand (kg/m^3)	Super plasticizer (kg/m^3)
Control	100	0	550.0	220	0.00	880	760	4
5P	95	5	522.5	220	27.5	880	750	4
10P	90	10	495.0	220	55.0	880	740	4
15P	85	15	467.5	220	82.5	880	730	4
20P	80	20	440.0	220	110.0	880	720	4
25P	75	25	412.5	220	137.5	880	710	4
30P	70	30	385.0	220	165.0	880	700	4

Table 3 shows the mixing characteristics of mortars. The mixing method used in making mortars is based on the proposed method of ASTM C305 and with some modifications (due to the presence of pozzolanic materials and the use of superplasticizers) inspired by the existing articles on the use of pumice in concrete. Self-compacting according to the following instructions:

- Cement, sand, and gravel were mixed at medium speed (80 rpm) for 1 minute.
- Pumice seeds and 30% water was added to the mixture and mixed at high speed (120 rpm) for 1 minute.
- The mixture was then allowed to rest for 1.5 minutes.
- After that, 70% of the remaining water was added with a superplasticizer and mixed for 2 minutes.

To make the results comparable, in making the samples, we tried to stay as stable as possible (within the EFNARC recommended range). The ratio of water to cement in all mixtures was considered 0.4. Pumice light grains were used as a substitute for some of the cement used. According to the concrete construction standard, all samples should be kept in the formwork for 24 hours and then taken out of the formwork and kept in a water tank with a temperature of 2 ± 20 ° C until the tests.

2.4. Fresh concrete tests

To measure the performance of self-compacting concrete in fresh concrete, several tests have been described by different regulations, which according to the available laboratory facilities, the following tests were performed:

- Slump flow test: Like ordinary concrete slump test, concrete is poured into an incomplete cone and after removing the incomplete concrete cone, it flows and spreads completely in the slip tray, unlike ordinary concrete, which almost retains its shape. This condition spreads two diameters of concrete and the time when the concrete reaches a diameter of 50 cm is measured and obtained as parameters of this test (Fig. 3).
- V-shaped funnel test: In this test, fresh concrete is poured into a special funnel whose bottom is closed and after filling the funnel and after 10 seconds, the bottom of the funnel opens and it takes time for the concrete to come out of the funnel. Be measured and introduced as a parameter of this experiment (Fig. 3).

- L-shaped box test: In this test, the upper part of the box, the bottom of which is closed by hatches, is filled with concrete.

After a while, the lower valve opens and while the front of the valve is a few rebars, the concrete flows and moves in the horizontal part of the box to settle, and for this test, it is time for the concrete to reach the distance. 20 and 40 cm of the valve in the horizontal part as well as the ratio of the height of the concrete at the beginning of the box to the height of the concrete at the end of the box after the settlement of the parameters are noted (Fig. 4).

3. Results and Discussions

3.1. Compressive strength test

Compressive strength test according to ASTM C109 was performed on 10 cm cubic specimens for 28 and 90 days. Concrete was made according to the instructions in the sample-making section. The samples were poured into the molds without any pressure and vibration after lubrication of the inner surfaces of the molds and they filled the mold under the influence of their weight. Cube molds should be removed from the mold after 24 hours and kept in a water tank with a temperature of 2 ± 20°C until the compressive strength test. Before loading, the surfaces of the samples were cleaned and dried, and the loose rock grains and particles that were stuck on them were removed. The load was applied to the flat faces of the sample that were in contact with the mold body. The sample was carefully placed under the test machine and in the middle of its jaws. According to the standard, no intermediate material should be used as a bed or cushion between the sample and the jaws of the device. The loading speed according to the standard should be in the range of 900 to 1800 Nm, which in the tests, this parameter was considered 1000 Nm. Loading was done by Controls hydraulic jack model 50-C5800. For samples in which the cross-section was more than 1.5% different from the nominal value, the actual cross-section was used to determine the compressive stress. The final compressive strength was calculated based on the mean resistances of the 3 samples. According to the standard used, specimens whose strength differs by more than 8% from the average strength of similar specimens made of the same concrete and tested at the same age should be eliminated. If less than 2 samples for each age remain after removing some of the test values or samples, the test should be repeated.

3.2. Flexural strength test

Flexural strength test was performed on prismatic specimens 20×5×5 cm for 28 and 90 days which the requirements is presented in ASTM C348 were tried to be observed as much as possible. The method of making concrete is mentioned in the section for making samples.

The inner surfaces of the formwork in contact with the concrete were coated with a thin layer of oil. After mixing the concrete, like cube samples, the concrete was poured into the molds without any pressure, then the surface of the samples was smoothed by a trowel. The specimens were kept in the same conditions as the compressive strength test specimens. Prior to flexural strength testing, the prism specimens were dried and the grains and loose particles adhering to the specimen surfaces that came into contact with the supports and load points were cleaned. After placing the prismatic specimens on the supports set at a distance of 17 cm, loading was applied through the loading blade perpendicular to the length of the prism. The loading speed was set at 44 Nm.

Water absorption test: The amount of water absorption of a cementitious composite indirectly indicates the porosity and reflects the volume and extent of capillary cavities in it which according to ASTM C642 was performed on 10 cm cubic specimens at 90 days of age. Two cubic samples were made from each mixture and the final water absorption was calculated based on the average of the water absorption values obtained for each sample. After 90 days of storage, the samples were taken out of the water and after gradual drying in the laboratory, to determine the dry weight at 110 55°C for 24 hours. The samples were then taken out and weighed by a digital scale. They were then placed in it for another 24 hours and then weighed. This trend continued until the difference between the 2 consecutive weights was less than 5% of dry weight. The last weighing was then recorded as the dry weight of the sample. After gradual cooling in the laboratory, the samples were returned to the water tank to absorb moisture. After 48 hours out of the tank and after drying the surface, moisture was weighed with a dry towel. Then they were returned to the water tank and after another 24 hours, they were taken out and weighed. This process continued until the difference between the values obtained from 2 consecutive weights became less than 5% heavier than the sample weight. At the end of the experiment, the last weight was recorded as saturation weight and the amount of water absorption was calculated.

Petrographic test: Concrete petrography is an effective method for evaluating the quality, performance, durability, and defects of concrete, which includes microscopic examination and dissection of hardened concrete in the laboratory using specialized lithological techniques used to study the stones. One of the advantages of using petrographic testing is that this method reduces or eliminates the need to use other more expensive tests by carefully examining selected samples and the control sample. Many types of materials, such as materials that result from the hydration of cement or adverse reactions and internal properties, can be detected by petrography. With the help of this method, the ratio of the main constituents of concrete can be obtained with high accuracy. This method can also be used to evaluate the effectiveness of some concrete restoration methods.

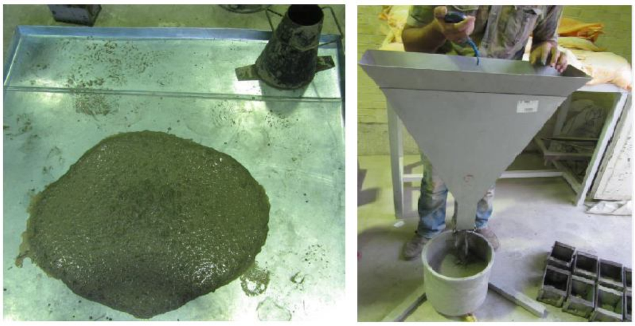

Figure 3. Slump flow measuring device (left) and V-shaped funnel (right)

Figure 4. L-shaped box test measuring device

To prepare self-compacting concrete, to prevent the fillers from being wasted during the mortar spin, first wet the inside of the mixer and then rotate the stone material in the mixer for 3 minutes to absorb a large amount of moisture from the inside body and prevent Avoid wasting materials. In this study, self-compacting concrete tests based on EFNARC were performed (EFNARC, 2002). Accordingly, the stability and filling of self-compacting concrete are defined by its four main characteristics of flowability, viscosity, permeability, and resistance to separation (EFNARC, 2002). Each of these parameters is estimated by one or more experiments. In this study, according to the prerequisites required for slump flow tests, the time to reach a diameter of 50 cm (T_{50}), a V-shaped funnel, and an L-shaped box have been selected. Slump flow testing is performed to determine flowability and filling capability at the horizon when there is no obstacle. The test is based on the principle on which the standard slump test is based. The diameter of the circle that the concrete makes after spreading will be a measure of the flowability of the concrete. According to EFNARC (EFNARC, 2002), the flowability of self-compacting concrete is divided into three categories, the details of which are shown in Table 4. Viscosity by definition refers to the resistance to the flow of fresh concrete when flow begins, which is usually the case for areas with bulky reinforcement and when concreting surfaces are required. In this study, the passage time of the V-shaped funnel and T50 is used to estimate the viscosity of self-compacting concrete. According to EFNARC (2002), there are two categories of self-compacting concrete viscosity, which are shown in Table 4. The L-shaped box measures the ratio of the height of the concrete passing through two or three reinforcements with a known diameter and distance after passing a certain distance. This test will evaluate the ability of fresh concrete to fill and pass through confined spaces and dense reinforcement without leaving the concrete integrity as well as any separation or blockage. The results of slump flow tests, time to reach the diameter of 50 cm (T_{50}), V-shaped funnel and L-shaped box for different self-compacting concretes are given in Table 4 and their changes are shown in Figures 5 to 8. All samples were designed to reach the SF2 class slump flow diameter obtained by adjusting the amount of superplasticizer. Therefore, all fresh mixes have the slump flow diameter recommended by EFNARC (2002). It should also be borne in mind that with the allowable ceiling, the amount of superplasticizer has been added to such an extent that the samples do not become waterlogged or detached.

Variations in slump flow in pumice-containing self-compacting concrete mixes are shown in Figure 5. As can be seen, the amount of slump current varies in the range of 670 to 685 mm. It is clear from Fig. 5 that with increasing the amount of pumice up to 10%, the flow rate of the samples increases and decreases to more than 10% of this component, and in mixtures containing 25 and 30% pumice, the flow rate increases. The slump is also lower than the control sample. In a similar study, Kabay et al. (2015) concluded that the slump flow rate of samples containing 20% pumice was reduced compared to the sample without pumice. The effect of different pumice replacement values on T50 time is shown in Figure 6. As can be seen, the T50 time varies in the range of 2.01 to 4.1 seconds for samples containing pumice. Fig. 6 shows that increasing the amount of pumice up to 10% reduces the time T50 and increasing the amount of pumice increases the time to reach the diameter of the slump flow by 50 cm. However, the T50 time for all mixes is between 2 and 5 seconds. In this range since T50, the viscosity of the mixture is high enough to increase the separation resistance as well as to limit the excessive pressure on the mold (Barfield and Ghafoori, 2012). A T50 time of fewer than 2 seconds can cause detachment, and a time of more than 5 seconds can increase the likelihood of blockage.

Table 4. Results of fresh concrete tests

Mixed	L-shaped box	V-shaped funnel flow time (sec)	Time to reach a 50 cm (sec)	Slump current diameter (mm)
Control	0.87	13.0	4.10	675
5P	0.88	11.9	3.10	678
10P	0.94	8.80	2.01	685
15P	0.91	9.10	2.59	680
20P	0.88	11.8	3.84	677
25P	0.88	12.3	3.95	674
30P	0.86	14.6	4.21	670

The passage time of the V-shaped funnel in self-compacting concrete samples is also estimated and the results are shown in Fig. 7. This time varies from 8.8 to 14.30 seconds for self-compacting concrete containing pumice. Only the sample containing 30% pumice had a higher time than the control sample to pass through the V-shaped funnel and the flow time of other samples containing pumice was reduced compared to the control sample. This means the presence of pumice up to 25% can increase the efficiency of the mixture.

According to Felekoglu et al. (2007) self-compacting concrete mixes with a V-hopper passage time of more than 20 seconds are not accepted. They claimed that these mixtures, due to their high viscosity, tend to trap air inside them. This means that the desired compaction capability is not achieved in these mixtures. However, self-compacting concrete mixes containing pumice have a V-hopper passage time of fewer than 20 seconds. It was mentioned earlier that EFNARC (2002) has divided the self-compacting viscosity of concrete into two groups based on V-shaped funnel passage times: VS1/VF1 and VS2/VF2. Details of T_{50} times and the passage of the V-shaped funnel for pumice-containing concrete for classification into these two groups are shown in Figures 5-4. Based on this, all self-compacting concrete samples are classified in VS2/VF2 group. It is noteworthy that this category of self-compacting concrete with slump flow class SF2 can be used in a variety of concrete ramps and piles. Fig. 8 showed that there is a good relationship between the passage time of the V-shaped funnel and the time when the concrete diameter reaches 50 cm for self-compacting concrete containing pumice. This relationship is a polynomial in the following form. Fig. 9 shows the effect of using pumice on the self-compacting concrete structure on the degree of blockage ratio. Self-compacting control concrete has an occlusion ratio of 0.87, which varies in the range of 0.86 to 0.94 by replacing different percentages of pumice. According to EFNARC (2002), a low obstruction ratio of 0.8 is not recommended. Pumice-containing self-compacting concrete mixes also have an occlusion ratio higher than 0.8 (recommended by EFNARC).

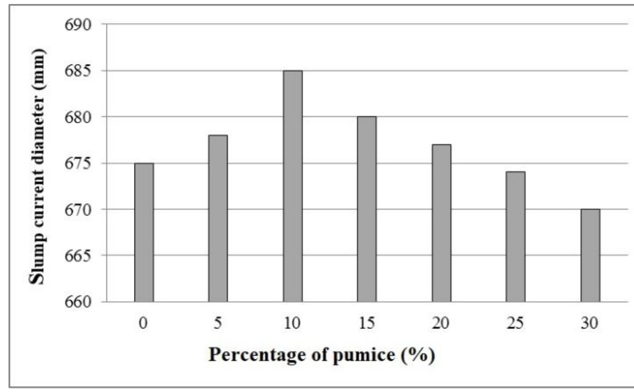

Figure 5. Slump test results

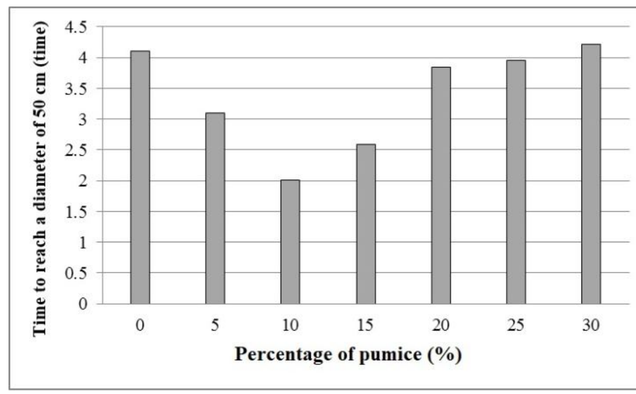

Figure 6. T50 test results

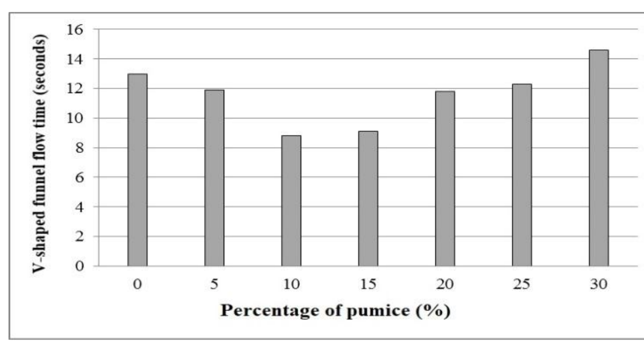

Figure 7. V-funnel test results

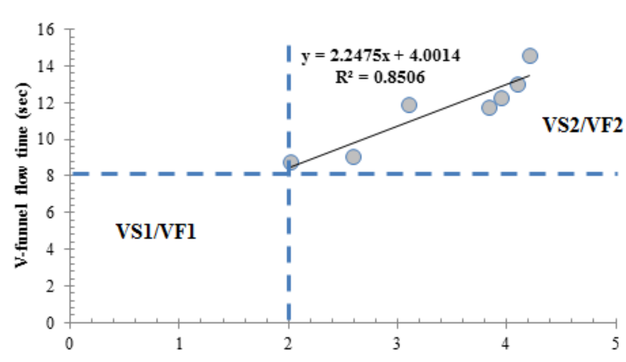

Figure 8. Relationship between passage time and flow of self-compacting samples

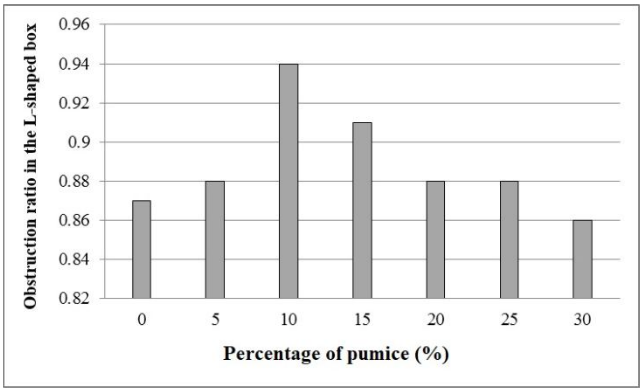

Figure 9. L-box box test results

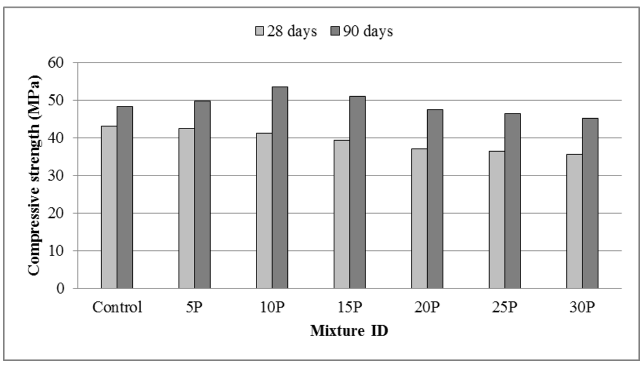

Figure 10. Compressive strength test results

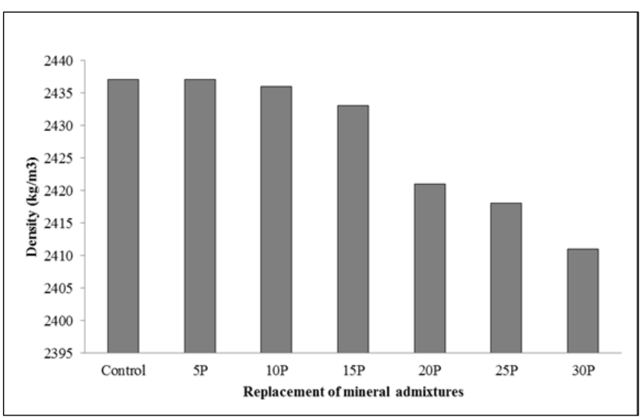

Figure 11. Specific weight test results

The compressive strength of self-compacting concretes with different percentages of cement substitute pumice was studied at 28 and 90 days of age, and the results of this experiment are shown in Fig. 10. In all designs, the compressive strength of the samples increases with the age of the concrete. Also, due to the fact that different percentages of these pozzolanic materials have been used, the optimal percentage has been obtained according to the mixing design used in this research. Based on this, the compressive strength of all samples varies from 35.6 to 53.6 MPa. As shown in Figs. 5 and 6, the addition of pumice to self-compacting concrete at 28 days of age reduces its compressive strength. This reduction in the sample containing 30% pumice reaches 17%. It is observed that at the age of 90 days, increasing the amount of pumice up to 10% increases its compressive strength by 11% and by adding more than 10% of pumice, the amount of resistance decreases. This reduction in a sample containing 30% pumice reaches 6%. In a similar process, Sarıdemir et al. (2013) by examining the compressive strength of concrete containing pumice showed that the highest increase in compressive strength of concrete for samples containing 10% pumice. This trend could indicate that the hydration reactions of cement are faster than the pozzolanic reactions, because at the age of 28 days, the control sample has more resistance and gradually, with the completion of the pozzolanic reactions, we see an increase in resistance. This increase in strength is achieved while the specific gravity of samples containing pumice is slightly reduced. In the figure below, it can be seen that the specific gravity of the samples containing pumice was reduced compared to the control sample. This can be effective in lightening the structures and reducing the effective force of the earthquake. In this regard, Sarıdemir et al. (2013) reported that with increasing the amount of pumice, the specific gravity of the samples decreases (ASTM C295 / C295M-19). Since the water absorption percentage of pumice is low, the use of pumice in concrete reduces the ratio of water to cement. Therefore, this will increase the compressive strength. It should be noted that the main factor in increasing the compressive strength of the samples is the high strength of pumice aggregates and reducing the water to cement ratio is of the next importance.

The flexural strength of self-compacting concrete containing pumice at 28 and 90 days of age is calculated and the results are shown in Table 6 and Fig. 12. A trend similar to that seen in compressive strength is also observed in flexural strength. For example, as in compressive strength, the greatest increase in flexural strength occurred in specimens containing 10% pumice at 90 days of age. Also, the resistance of the samples decreased at the age of 28 days compared to the control sample, which could be due to the low activity of pumice compared to cement. But in 90-day samples, we see a 19% increase in samples containing 10% pumice. But with the increase of pumice up to 30%, the flexural strength has decreased.

Table 5. Compressive strength test results

No.	Mixed	Compressive strength (MPa)	
		28 Days	90 Days
1	Control	43.1	48.3
2	5P	42.6	49.9
3	10P	41.3	53.6
4	15P	39.3	51.1
5	20P	37.0	47.6
7	25P	36.5	46.5
8	30P	35.6	45.2

Table 6. Flexural strength test results

No.	Mixed	Flexural strength (MPa)	
		28 Days	90 Days
1	Control	7.25	8.59
2	5P	7.15	9.12
3	10P	7.12	10.25
4	15P	7.00	10.14
5	20P	6.89	9.74
7	25P	6.65	9.68
8	30P	6.55	9.42

Table 7. Water absorption test results

No.	Mixed	Water absorption (%)
1	Control	6.3
2	5P	6.1
3	10P	6.0
4	15P	6.3
5	20P	6.7
7	25P	7.1
8	30P	7.3

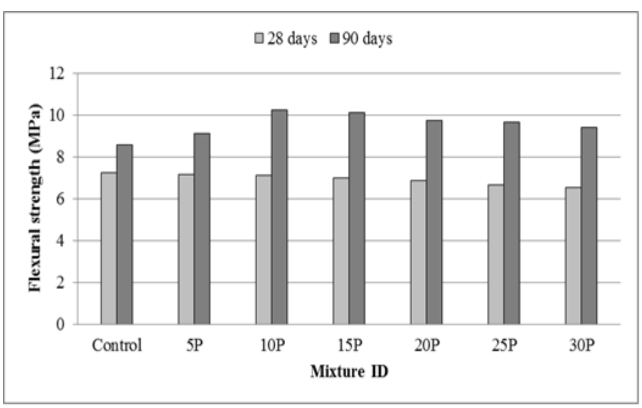

Figure 12. Flexural strength test results

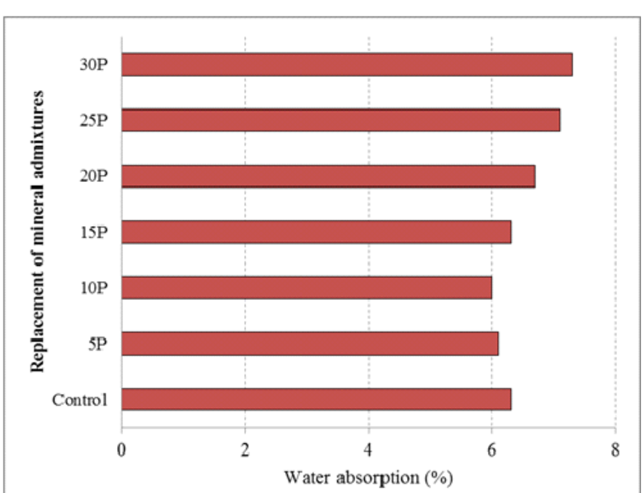

Figure 13. Water absorption test results

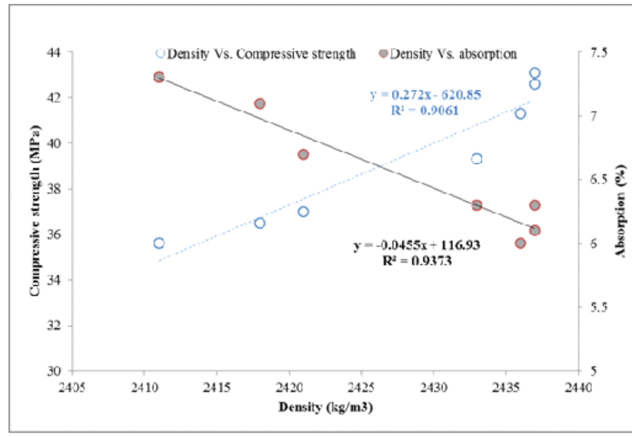

Figure 14. Relationship between compressive strength, specific gravity and water absorption of self-compacting concrete containing pumice

The 90-day water absorption of self-compacting concrete was calculated and as shown in Table 7 and Fig. 13, the addition of pumice up to 10% to self-compacting concrete reduced water absorption compared to the control sample, but added Adding 15 to 30% of pumice to concrete has slightly increased water absorption, which is not desirable. This may be due to the pumice not fully spreading in the concrete. The results of water adsorption test show that fine pumice grains fill the cavities in concrete to create a denser microstructure, which in turn reduces porosity and adsorption properties and therefore expects improved concrete durability by preventing the adsorption of harmful chemicals.

To better understand the relationship between the properties of self-compacting concrete, compressive strength and water absorption, self-compacting samples containing pumice against their specific gravity are shown in Fig. 14. The increase in specific gravity is generally directly related to the compressive strength, while the specific gravity and water absorption are inversely related to each other. From Fig. 14, it can be seen that the correlation between compressive strength and specific gravity as well as water absorption test and specific gravity is very high and the correlation coefficient of 0.93 and 0.9 can be observed, respectively. The reason for the lower correlation coefficient between specific gravity and water absorption can be due to differences in their mechanism, which is influenced by many factors. For example, the transition zone can be considered as one of the important factors in the compressive strength test, but this issue is not very important in water absorption.

4. Conclusion

Results of the study can be presented as:

A) The amount of slump current varied in the range of 670 to 685 mm. With increasing the amount of pumice up to 10%, the flow rate of the samples increases and with increasing more than 10%, this component decreases and in mixtures containing 25 and 30% of pumice, the slump flow rate of the control sample also decreases.

B) Increasing the amount of pumice up to 10% reduces the time of T50 and by increasing the amount of pumice increases the time to reach the diameter of the slump flow by 50 cm. However, the T50 time for all mixes is between 2 and 5 seconds.

C) The passage time of V-shaped funnel in self-compacting concrete samples was also estimated. This time varies from 8.8 to 14.30 seconds for self-compacting concrete containing pumice. Only the sample containing 30% pumice has a higher time than the control sample to pass through the V-shaped funnel and the flow time of other samples containing pumice has been reduced compared to the control sample. This means the presence of pumice up to 25% can increase the efficiency of the mixture.

D) All self-compacting concrete samples are classified in VS2 / VF2 group. It is noteworthy that this category of self-compacting concrete with slump flow class SF2 can be used in a variety of concrete ramps and piles.

E) There is a good relationship between the passage time of the V-shaped funnel and the time when the concrete diameter reaches 50 cm for self-compacting concrete containing pumice.

F) The self-compacting control concrete had an occlusion ratio of 0.87, which varies in the range of 0.86 to 0.94 by replacing different percentages of pumice.

G) Adding pumice to self-compacting concrete at the age of 28 days reduces its compressive strength. This reduction in a sample containing 30% pumice reaches 17%.

H) At the age of 90 days, increasing the amount of pumice up to 10% increases its compressive strength by 11% and by adding more than 10% of pumice, the amount of resistance decreases. This reduction in a sample containing 30% pumice reaches 6%.

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