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Effect of Natural Zeolite Content on The Properties of Self Consolidating Concrete

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Abstract

Self Consolidating Concrete (SCC) is one of the considerable progresses in concrete technology. Since the first developments in the late 1980s in Japan, many research works are done in order to investigate the fresh and hardened properties of SCC. While the main focus in optimizing SCC mixture components is on rheological properties, the hardened properties, mainly in terms of strength and durability parameters, are also of great importance.

Keywords:scc, concrete, zeolite, self consolidating

1.Introduction

According to Juvas [Juvas K. Experiences with SCC in the production of prefabricated elements. In: Wallevik O, Nielsson I, editors. Proceedings of the 3rd international RILEM symposium, Reykjavik, Iceland; 2003.] while materials for SCC are 15–25% more expensive than those of normal concrete of the same strength grade, the total costs will be 5–15% lower when all savings in work are considered.

The other main advantages of using SCC in building structures includes enhancing construction productivity, improving the work environment, achieving sustainable characteristics, increasing the practically allowable reinforcement rate, and increasing the construction rate and overall quality of the cast structures [Zhu W, Gibbs JC, Bartos PJM. Uniformity of in situ properties of self-compacting concrete in full scale structural elements. Cem Concr Compos 2001;23(1):57–64. & Bartos PJM. Measurement of key properties of fresh self-compacting concrete. In: Measurement, testing and standardization: future needs in the field of construction materials, proceedings, Paris, 5–6 June; 2000. & Almeida Filho FM, El Debs ALHC. Pull-out behavior of deformed bars using high strength self-compacting concrete and high strength ordinary concrete. Ibracon Struct J 006;2(1):44–55].Furthermore, SCC is known to impart a more homogeneous and dense microstructure, compared to conventional concrete, therefore leading to more durable reinforced and pre-stressed concrete structures [combined effect of two sustainale…..] These benefits which are reaped through use of SCC, have caused rapid development of this kind of concrete in different countries.

Since SCC advantages are the results of it's fresh properties, these properties are of higher importance in SCC comparing with conventional concrete. In order to fulfill self compactibilty, fresh concrete must have three main characteristic which are filling ability, resistance to segregation and passing ability. The requirements for all the three characteristics should be fulfilled for a fresh concrete to be classified as SCC. Hence, various tests are designed to evaluate the fresh properties of SCC according to these three criterions [EFNARC, The European Guidelines for Self-Compacting Concrete, May 2005.<www.efnarc.org>.]

Concrete for the 21st century have to be more durable, easier to apply, more predictable and greener. At the same time it will have to be more cost competitive. [Shah SP, Akkaya Y, Bui VK. Innovations in microstructure, processing and properties. Innovations and Developments in concrete Materials and Construction. In: Dhir Ravindra, Hewlett Peter C, Csetenyi Laszlo J, editor. Proceedings of the international conference held at the University of Dundee, Scotland, UK, 9–11 September 1999.] Reducing cement content in a SCC mixture can lower the production cost and is also desirable from environmental point of view. [+Autogenous cracks] Use of supplementary cementitious materials (SCM) is a popular solution to both reduce cement content and also improve durability of hardened SCC.

Application of supplementary cementitious materials (SCM) as partial replacement of Portland cement appeared in SCC mixtures during the last two decades only; previously, for instance fly ash and silica fume were considered as mere microfillers [Persson B. A comparison between mechanical properties of self-compacting concrete and the corresponding properties of normal concrete. Cem Concr Res 2001;31:193–8.]. At first, the main motivation for using SCM was cost reduction. More recently, as environmental arguments began to prevail, in particular the need to decrease the overall CO2 production related to the use of cement in concrete[Habert G, Roussel N. Study of two concrete mix-design strategies to reach carbon mitigation objectives. Cem Concr Compos 2009;31:397–402. & ghiasvand], SCM are more considered and more research work has to be done on different SCMs and their effects on both fresh and hardened properties of SCC.

Fly ash, ground granulated blast furnace slag and silica fume are the most frequently applied SCMs in SCC.[properties of scc mixture containg MK] One of other supplementary cementitious materials which, to the authors knowledge, is rarely used in SCC before, is natural zeolite. Natural zeolite as volcanic or volcano-sediment material has a three dimensional frame structure and is classified as a hydrated aluminosilicate of alkali and alkaline earth cations. Crystals are characterized by a honeycomb like structure with extremely small pores and channels, varying in size from 3 x 10^–4 – 4x10^-4 µm. It has an equivalent total specific surface (internal and external) area of 35–45 m2/g [Mumpton FA, editor. Mineralogy and geology of natural zeolites. New York: Reprint of Mineralogical Society of America's Reviews in Mineralogy; 1993.].

Another approach to lower the cement content in a SCC mixture is "dense particle packing" idea. By reducing the void between aggregates, the paste volume needed to fill the space decreases and it can result in reduction in cement content. It was observed from [Glavind M, Pedersen EJ. Packing calculations applied for concrete mix design. In: Proceedings of creating with concrete. Dundee; 1999. p. 1–10.] that the aggregate combination with maximum packing density significantly influences the properties of concrete, apart from economic benefit.

Mueller et al. [Effect of Limestone Filler Addition in Eco-SCC] reported a SCC mix design with a good rheology and stability containing only 220 kg/m3 of Portland cement and 100 kg/m3 of limestone filler. They have lowered the cement content through increasing w/c ratio up to 0.88 (VOLUME????) which may cause durability problems in the so-called mixture.

In this article the use of different contents of natural zeolite as SCM in SCC is studied. Besides, the cement content is lowered due to the experimental method used for grading aggregates and use of natural zeolite as SCM and limestone filler. Beside fresh properties of SCC mixtures, some of the hardened properties are investigated.

2.Experimental plan

Materials

The cement used was ASTM C 150 type I Portland cement. Zeolite from eng.ahmadi article

The superplasticizer used in order to reach the slump flow needed for SCC, was a ''polycarboxylic'' based admixture, commercially branded as Glenium51P. It is an F-type high-range water reducer, in conformity with ASTM C 494. [ASTMC 494-99a. Standard specification for chemical admixtures for concrete. Annual book of ASTM Standards, 2002.] Solid content, pH and specific gravity of the admixture are 546654%, 65465465 and 65465465, respectively.

Natural sand and crushed gravel were used as aggregates. The specific gravity and water absorption properties of river sand and crushed gravel are 2.71, 2.6%, and 2.57, 1.6%, respectively.

In order to reach the desired characteristics in fresh SCC, three approaches are available. First is using a high quantity of fines which give the viscosity needed for SCC mixture. Second is using viscosity modifying agent (VMA) instead of increasing fine content and the third approach is using both VMA and high quantity of fines in SCC composition. Since VMA is not manufactured in Iran and is economically undesired, it was decided to add limestone filler passing #50 sieve (10% of sand content, by weight) to increase the fine content of mixture and enhance it's viscosity.

3.Mixture proportions

To investigate the effect of natural zeolite content on fresh and hardened properties of SCC, cement was replaced by zeolite in five different levels: 10,15,20,25 and 30 percent of weight of total cementitious materials which was kept constant at 350 kg/m3. Also a control mixture which didn't contain any zeolite was designed. The water to cementitious materials ratio was chosen 0.45 in all mixtures. The mix proportions are given in Table 1.

Table 1- Mix proportions of SCC mixtures

Mix ID	Natural zeolite replacement (%)	w/cm ratio	Cement (kg/m3)	Sand (kg/m3)	Gravel (kg/m3)	Limestone filler (kg/m3)
CTRL	0	0.45	350	1294	535	125
Z10	10	0.45	315	1240	531	124
Z15	15	0.45	297.5	1237	530	124
Z20	20	0.45	280	1233	528	123
Z25	25	0.45	262.5	1228	526	123
Z30	30	0.45	245	1224	525	122

4.Fresh concrete tests

As mentioned before, fresh SCC should have the requirements for all the three main characteristics needed for being self-compactible viz. filling ability, passing ability and segregation resistance. In order to evaluate these workability parameters, the slump flow test and T50 time (filling ability), J-ring test -flow diameter and difference in concrete height inside and outside J-ring (h2–h1)- (passing ability) and GTM screen stability test (segregation resistance) were conducted on fresh mixtures in accordance with EFNARC. [EFNARK] The EFNARK test method for evaluation of segregation resistance, GTM screen

stability test, consists of taking a sample of 10 liters of concrete, allowing it to stand for 15 minutes to allow any internal segregation to occur, then pouring half of it on to a 5mm sieve of 350mm diameter, which stands on a sieve pan on a weigh scale. After two minutes, the mortar which passed through the sieve is weighed, and expressed as a percentage of the weight of the original sample on the sieve.
It should be considered that Self-compactibility test method stipulations are not universally accepted rules. Degree of toleration depends on the engineering judgement, material type and variety. [Effect of w/c ratio …..]

5.Hardened concrete tests

Although fresh properties of SCC are of high importance and result in benefits mentioned before, these are hardened properties of concrete that structural engineers are interested in and these properties determine service life of concrete structures. In order to evaluate the hardened properties of SCC mixtures, compressive strength test, Rapid Chloride Penetration Test (RCPT) and electrical resistivity test were conducted on the specimens cast from SCC mixtures containing different contents of natural zeolite.

6.Compressive strength test

Three concrete cubes of 100 x 100 x 100 mm dimension were cast for conducting compressive strength test in each age. This test was done in 7, 28 and 90 day specimens in order to investigate natural zeolite content effect on the compressive strength of concrete, the most common characteristic to determine quality of a mixture.

7.RCPT test

Corrosion of steel reinforcement in concrete is a major aspect affecting concrete durability. When concrete is subjected to a chloride-rich environment, the chloride ions can penetrate and diffuse through the body of the concrete, ultimately reaching the steel bars and causing corrosion. [Corrosion resistance of ….] For instance, this phenomenon is the main cause of great economical damages in Persian Gulf region concrete structures. Low permeability and dense microstructure are the key characteristics which can reduce the rate of this process and consequently increase the structure service life. In order to evaluate the ability of low-cement SCC mixtures to resist chloride ion penetration, ASTM C1202 test method was conducted on two specimens of each mixture at the ages of 28, 56 and 90 days.
The ASTM C1202 method consists of monitoring the amount of electrical current passed through a 100 mm diameter by 50 mm thick concrete specimen, when a potential difference of 60 V is maintained across the specimen for a period of 6 h, Chloride ions are forced to migrate out of a NaCl solution subjected to a negative charge through the concrete into a NaOH solution maintained at a positive potential.
The conditioning of the concrete disc specimens for the test procedure consists of 1 h of air drying, 3 h of vacuum (pressure <600 mm Hg), 1 h of additional vacuum with specimens under deaerated water, followed by 18 h of soaking in water. The total charge passed, in coulombs, is used as an indicator of the resistance to the passage of chloride ions, the lower it is, the more resistant is the concrete to chloride penetration. [ASTM C1202]

8.Electrical resistivity

The electrical resistivity meter was used to measure the surface resistivity at the ages of 28 and 90 days. 100x200 mm cylinders were tested at each age while they were saturated. The electrical resistivity test for concretes was carried out by the four-point Wenner array probe technique. The resistivity measurements were taken at four quaternary longitudinal locations of the specimen as shown in figure 1.

Figure 1: longitudinal locations of the specimen

9.Test results and discussion

Fresh concrete test results

The results of the fresh concrete tests are given in table 654654654. EFNARC [EFNARC] introduces 65-80 cm and 2-5 s as acceptance criteria for SCC slump flow diameter (average of two perpendicular diameters) and T50 time. It also suggests 0-10 mm for (h2-h1) in J-ring test and 0-0.15 for segregation ratio in GTM screen test as acceptable ranges for fresh SCC mixture test results.
It should be mentioned that slump flow diameter was held in the range of 70±3 cm (except for control mix) by adding different dosages of superplasticizer to mixtures. Superplasticizer content used for each mixture is presented in Table 2. It is observed that superplasticzer demand increases with higher level of cement replacement by natural zeolite, though viscosity of fresh mixture increases, which is in line with other research on conventional concrete containing natural zeolite.

Table 2- Fresh SCC test results

Mix ID	Superplasticizer (%)*	Slump flow test		J-ring test		GTM screen test
		Avg. of two dia.	T50 (sec)	Avg. of two	h2-h1 (mm)	Segregation

		(mm)		dia. (mm)		ratio (%)
CTRL	1.90	555	4.3	530	6	3.8
Z10	2.49	705	2.5	690	8	3.0
Z15	2.60	710	2.6	700	7	2.9
Z20	2.73	705	3.8	690	7	2.7
Z25	2.86	685	3.0	670	10	2.7
Z30	3.08	715	5.4	695	13	2.5

*superplasticizer percentage by cementitious materials mass

As it is seen in Table 654654654 the flow diameter needed for SCC wasn't resulted from the control mixture. In fact, when this mixture was being mixed, it was impossible to add anymore superplasticizer due to the observed bleeding and segregation. Moreover, J-ring test result confirmed low flowing ability of this mixture and approved the fact that this mixture can't be classified as SCC mixture. The reason of this poor fresh state behaviour was low viscosity and stability of the mixture which didn't tolerate any more addition of superplasticizer for improving filling ability of the mixture, which in turn, was the result of low cement content of the mixture.

The segregation ratio for all five mixtures containing natural zeolite was below 5%, which shows high segregation resistance of these mixtures. This is because of high viscosity of mixtures resulting from addition of limestone filler and natural zeolite. Besides, it can be observed that the maximum difference between slump flow diameter and J-ring flow diameter is 20 mm, showing the proper passing ability of five mixtures and approving their acceptable flowing ability. These mixtures have also fulfilled the requirements mentioned by EFNARK for SCC mixtures regarding T50 time and (h2-h1) in J-ring test, except for Z30 where corresponding results have slightly exceeded the upper limits. Considering the imprecise nature of these fresh tests and negligible difference between Z30 results and EFNARK acceptable measures, Z30 was considered as a SCC mixture.

Considering the fresh test results, all five mixtures containing natural zeolite were accepted as SCC mixtures and cylinder and cubic specimens were cast from these mixtures to assess their hardened properties. On the other hand, since control mixture was rejected at fresh state requirements, no specimens were cast from this mixture and hardened tests weren't conducted on it.

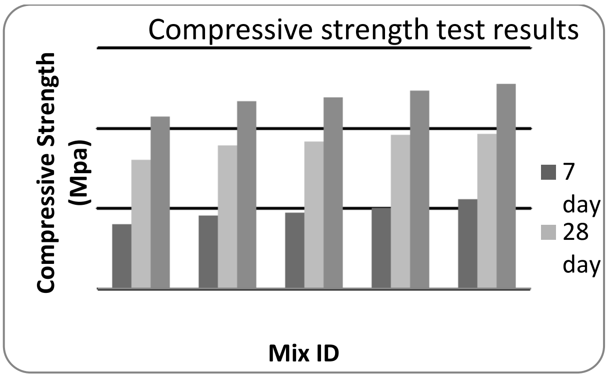
10.Hardened concrete test results

Compressive strength test

The compressive strength test was conducted on 100 mm cubic specimens, at the ages of 7, 28 and 90 days. It is clear that increasing the zeolite content has decreased the compressive strength in all ages. Still, a minimum of 40 MPa is achieved for 90 day specimens of all mixtures. Table3

Table 3- Compressive strength

Mix ID	Compressive strength (MPa)		
	7 day	28 day	90 day
Z10	22.3	38.7	51.0
Z15	20.2	38.3	49.5
Z20	18.8	36.7	47.7
Z25	18.2	35.8	46.8
Z30	16.2	32.0	43.0



11.RCPT test

Mix ID	RCPT results(Columb)					
	28 day	Chloride ion penetrability	56 day	Chloride ion penetrability	90 day	Chloride ion penetrability
Z10	2548	Moderate	1654	Low	1478	Low
Z15	2451	Moderate	1524	Low	1071	Low
Z20	1791	Low	1364	Low	775	Very low
Z25	1415	Low	889	Very low	646	Very low
Z30	1102	Low	729	Very low	419	Very low

12.Electrical resistivity test

Mix ID	Electrical resistivity (Kohm.cm)	
	28 day	90 day
Z10	15.50	30.25
Z15	21.00	39.75
Z20	26.00	52.25
Z25	35.25	69.50
Z30	44.25	95.25

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