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Research Article

PROPERTIES OF FRESH LIGHTWEIGHT SELF-COMPACTING CONCRETE CONTAINING EPS BEADS

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ABSTRACT
Construction of concrete structures always requires suitable inserting and appropriate compressing of the fresh concrete in the frame to reach adequate mechanical properties at hardened from of concrete. However, this issue even with existence of experienced workers and enough tools usually is not possible at ordinary concretes. In order to solve this problem, the idea of self-compacted concretes was introduced for the first time in Japan in 1986. Self-compacted concrete is a new generation of concrete with high ductility and enough strength against separation that can easily flow inside the frame and fill all corners of the frame and the space between the reinforcements without need to vibration and any compression. Self-compacted concrete compared with ordinary concrete has more cement materials, less coarse grain and more fine grain, which this fact increases its density. In this study, we tried to reduce the concrete density using expanded polyester seeds (EPS). These seeds were used in 3 sizes passing through the sieve 7, the sieve between 4 and 7 and the sieve 4. Seeds passing through the sieve 7 were replaced with s and 0-3, the sieve between 4-7with sand 3-6 and over the sieve 4 with gravel.12 different mixes with single and combined percent of replacement of EPS were made and slump test and V funnel test and L-Box test were performed on each mix. Finally, it was found that by adding the appropriate amount of super-lubricant, as well as adding silica fume and limestone powder to make viscous the concrete, we could satisfy all conditions of self-compaction without heaving and detachment.

Keywords: *Self-Compacted Lightweight Concrete, Expanded Polyester, Rheological Properties*

INTRODUCTION
Construction of concrete structures always requires suitable inserting and appropriate compressing of the fresh concrete in the frame to achieve the adequate mechanical properties of the concrete at hardened state. However, this issue even with existence of experienced workers and enough tools usually is not possible at ordinary concretes. Lack of skilled workers is always one of the important concerns in construction. In order to solve this problem, the idea of the self-compacted concrete was introduced for the first time in Japan in 1986. But, this idea was reached to production stage for the first time in 1988. Later, Japanese experts developed the technology of producing this type of concrete and used it extensively in structures and infrastructures. The use of self-compacted concrete during the last two decades in other countries of the world has expanded (Safiuddin *et al.*, 2012).
Self-compacted concrete is a new generation of concrete with high ductility and enough strength against detachment. This concrete is a special type of concrete that can easily flow within the frame and fill all corners of the frame and the space between the reinforcements without need to vibration and any compression (Mazaheripour *et al.*, 2011). Filling property, passing property and resistance to segregation are three essential factors of self-compacted concretes. The balance between these three factors should be carefully preserved in order to achieve self-compaction (Safiuddin *et al.*, 2012). One of the objectives of producing of the self-compacted concretes is to reduce the volume of cement used in concrete (Alexandre *et al.*, 2012).
Self-compacted concretes include the special additives such as super-lubricants, replacement cement materials (Pozzolans) and the viscosity improvers in comparison with conventional concretes. Similarly,

these concretes contain more cement materials, less water content, more fine grain and less coarse aggregates in comparison with the conventional concretes. The ratio of water in self-compacted concretes is less than conventional concrete. While the ratio of water in conventional concretes is usually greater than 0.4, it ranges from 0.25 to 0.4 in self-compacted concretes (Persson, 2001), (Safiuddin *et al.*, 2010). Addition of super-lubricants is one of the most critical requirements for producing self-compacted concretes. However, the addition of this substance improves the filling and passing properties of the concrete, but the overuse of it results in instability and detachment of the concrete (Safiuddin *et al.*, 2012).

One of the most determining factors in the design and construction of the concrete structures is the significant amount of dead load in these structures. For this purpose, the use of lightweight materials in the construction of the beams and columns and other structural components is necessary to reduce the dead load in the structure and the economic design. This issue resulted in production of lightweight concretes. Lightweight concretes require mix design and the special way of its construction that is completely different from conventional concretes (Mazaheripour *et al.*, 2011). Lightweight concrete is produced through various ways including the addition of air-producer materials such as aluminum powder, the use of light mineral aggregates such as Perlite, Vermicolite, Scoria, and Lica as well as addition of the expanded polyester seeds or other light polymer materials to the concrete (Siddique, 2011).

In this study, the expanded polyester seeds (EPS) as lightweight material were used in concrete. Studies on concretes containing EPS have been begun since 1913, when Cook introduced EPS as a light material applicable in concrete (Cook, 1973). EPS is frequently used in the packaging industry, due to this reason it is available in abundance and with low cost. It is while the other light weight aggregates due to their high costs impose more expenses to constructional projects. Since EPS has a lower specific weight, by changing the amount of it in concrete mix design we can produce a wide range of light concretes with special gravity and different mechanical properties to be used in structural and non-structural objectives.

In this study, to increase the viscosity of the concrete mixture, the limestone powder and to improve the adhesiveness between cement fume and EPS and to prevent the heaving these light aggregates, silica fume was used. Non-pozzolanic fillers such as limestone are used to improve the compaction of particles and ampacity behavior of cement paste in self-compacted concrete mixtures. The use of stone powder was originally developed from Sweden and France (Okamura and Ozawa, 1995; Okamura and Ouchi, 2003).

Silica fume is a very fine and amorphous (non-crystalline) material of silicon oxide type which is obtained in its production process with alloys of silicon element in electric furnaces. This material naturally has very strong pozzolanic properties that this property improves the finished and strengthening features of the concrete, but this pozzolanic material is very expensive (Okamura and Ozawa, 1995).

Consumables

In this study, the used cement is of Hegmatan type II. The used sand is also of the rounded river sand passed through the 12.5mm sieve (1.2) which is suitable for use in self-compacted concrete. Due to the use of 3 different sizes of EPS, the aggregates were also divided into 3 sizes that each aggregate was replaced with EPS materials approximately with the same size. For this purpose, the gravel was divided into two parts of 0-3 and3-6 sizes, that 0-3 gravel passing through sieve number 7 and the 3-6 gravel passing through the sieve number 4 and remained over the sieve number 7 were selected. Stone powder was also used as filler. Silica also was used by 10% of weight of cement in the project and was replaced it. The consumed supper lubricant is of Fercoplast P10-3R based on poly-carboxylate ether that was used in each project depending on the required amount. The consumed water was drinking water of the city of Rasht and the entire processes of testing from sieving the materials to concrete construction were carried out in the concrete laboratory of engineering department of Gilan University. As mentioned previously, EPS grains were used in 3 sizes. The fine size was named number 1 that is the type passed through the sieve number 7, the average size was named number 2 that is the type passed through the sieve number 4 and remained over the sieve number 7 and the coarse size named number 3 and remained over the sieve number 4. In Figure (1), these three sizes have been shown beside each other.

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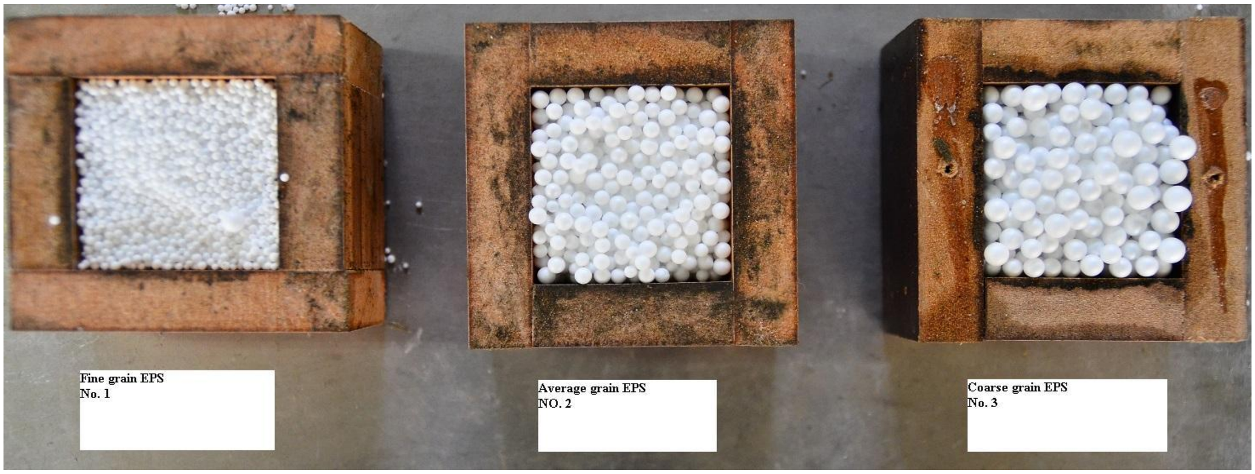

Figure 1: The used sizes of EPS

As mentioned above, any size of EPS became equivalent with an aggregate size. In this way, fine grain EPS or size 1was replaced with 0-3 sand, average EPS or size 2 with 3-6 sand, and coarse EPS or size 3 with gravel. It should be noted that all replacements were done according to volume (size). In general, these replacements were done in three different percents of 20%, 30% and 40% of the aggregate volume. Because of the uniformity of EPS grains and prevention of the disruption of the gradation, we concluded that it is better any EPS size is replaced with two aggregate sizes in order to the shortage of stone aggregates does not disturb the balance of the used materials in concrete. Therefore, in projects containing coarse EPS, the stony materials were replaced with the proportion of 75% sand and 25% of gravel of this lightweight material and in projects containing average EPS, the stony materials were replaced with proportion of 50% sand and 50% gravel and in projects containing fine EPS, the stony materials were replaced with proportion of 25% sand and 75% gravel. Similarly, in synthetic projects, the volume of every EPS size is obtained by multiplying the entire required volume in the weight proportion of aggregate with the same size of the EPS divided by total weight of the aggregate. Therefore, 13 mixes were made and the tests were carried out on each of them. The physical properties of aggregates and lightweight aggregates have been provided in table 1, and the chemical properties of cement and silica fume have been presented in table 2.

Table 1: Physical properties of materials

Name	**Cement**	**Silica fume**	**Gravel**	**0-3 sand**	**3-6 sand**	**Fine EPS**	**Average EPS**	**Coarse EPS**	**Stone powder**
Density (kg/m$^{3)}$	3150	2220	2650	2700	2680	0.295	0.0195	0.0135	2750

Table 2: Chemical properties of cement materials

Chemical composition (%)	**Cement**	**Silica fume**
SiO_2	21.16	91.1
Al_2O_3	4.85	1.55
Fe_2O_3	3.9	2.0
CaO	63.52	2.42
MgO	1.52	0.06
SO3	2.51	0.45
Na_2O+0.685K_2O	0.8	-
Na_{2O}	0.4	-

MATERIALS AND METHODS

The Method of Construction Specimens and Performing the Tests

All materials are kept in natural moisture conditions. For preparation the specimens, first the materials were weighed separately, are kept in bags in a suitable environment, and then were used in construction of concrete. In Table 3, we have quantitatively investigated the composition of mixes and the proportion of each stony material, lightweight aggregates, silica fume and stone and cement powder. It should be noted that all numbers are in kilograms and indicate the amount of each element in cubic meter of concrete.

Table 3: The compounds of mixtures (kg/m^{3}for concrete)

No.	Project's name	gravel	0-3 sand	3-6 sand	Cement	Silica fume	Stone powder	w/c	water	EPS replacement percentage	Coarse EPS	Average EPS	Fine EPS
1	E0	690	615	185	405	45	250	0.36	162	0	0	0	0
2	E1	285	515.5	152.5	405	45	250	0.36	162	20	2.565	0	0
3	E2	410.75	416.5	123.5	405	45	250	0.36	162	20	0	3.375	0
4	E3	536.75	317.5	94.5	405	45	250	0.36	162	20	0	0	56.05
5	E4	430.75	398.25	121.5	405	45	250	0.36	162	20	1.235	0.348	22.346
6	E5	96.25	466.5	138.5	405	45	250	0.36	162	30	3.85	0	0
7	E6	285	318	93.75	405	45	250	0.36	162	30	0	5.55	0
8	E7	473.75	168.75	50.5	405	45	250	0.36	162	30	0	0	84.075
9	E8	314.75	290.25	91.25	405	45	250	0.36	162	30	1.185	0.675	34.4
10	E9	0	370	75.5	405	45	250	0.36	162	40	5.125	0	0
11	E10	159	219.5	64	405	45	250	0.36	162	40	0	7.4	0
12	E11	410.75	20.25	6.75	405	45	250	0.36	162	40	0	0	112.1
13	E12	198.75	182.5	60.75	405	45	250	0.36	162	40	2425	0.875	46.275

To prepare the specimens, first the stone materials were poured into a mixer and then the half amount of water needed for the mix project was added to it and were mixed for few minutes well. Since the EPS grains are too light, they rapidly flee out of the mixer. Due to this reason, the grains are added to the mix after the sand and gravel were mixed together and impregnated in order the moisture does not make the grains stick to each other. However, despite this issue after adding EPS to the mix, the mouth of the mixer was covered to prevent the possible departure of EPS grains. Then, after the mixing of these seeds with sand and gravel for a few minutes, the cement and silica fume were added to the mix and still by covering the door of mixture the mixing was continued for one minute. Then the supper-lubricant was added to the remained water and was added to the mix. At this stage, due to addition of cement and stickiness of the mix, covering the mixture's door was needed no longer. After 3 to 4 minutes of mixing the mixture, if needed, the supper-lubricant was added; otherwise, the mixture starts the self-compaction phase.

RESULTS AND DISCUSSION

Fresh Concrete Testing and the Results

When the fresh concrete was mixed well, the experiments of self-compacted concrete were carried out. These tests include slump, V-funnel and L-Box. The results of these tests are presented in Table 4.

Generally, designs containing combined EPS, that is, the projectsE12, E8, and E4 show rheological properties.

This may be because of this issue that all 3 sizes of light weight aggregates have been used and this uniformity of the non-cement materials keeps the rheological properties of the concrete. In designs containing Size1 EPS (fine grains), a little heaving was observed that is negligible.

This heaving was due to the smoother surface of this size of light weight aggregate compared with two other sizes which less adhesion is created between its surface and the cement mix.

As we know, EPS grains all are produced from a similar size grain and are changed to different sizes depending on the temperature at which they become mature. Therefore, it is normal that the more the temperature increases and the size becomes larger, the more the likelihood of the creation of microscopic cracks is seen on the surface of these seeds which increases the adhesion between the cement mix and this aggregate.

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Table 4: Test results of self-compaction tests

No.	Project's name	Slump(cm)	V-funnel(s)	Ratio of L-Box
1	E0	75	11	1
2	E1	70	9	0.95
3	E2	72	9	0.9
4	E3	67	9	0.8
5	E4	70	10	1
6	E5	70	11	0.9
7	E6	70	9	0.9
8	E7	68	7	0.85
9	E8	75	11	1
10	E9	69	9	0.95
11	E10	66	10	0.9
12	E11	63	8	0.85
13	E12	70	7	1

After the combining designs, the designs containing coarse EPS showed better rheological properties. An example of a slump test on the concrete containing coarse EPS is shown in Figure 2.

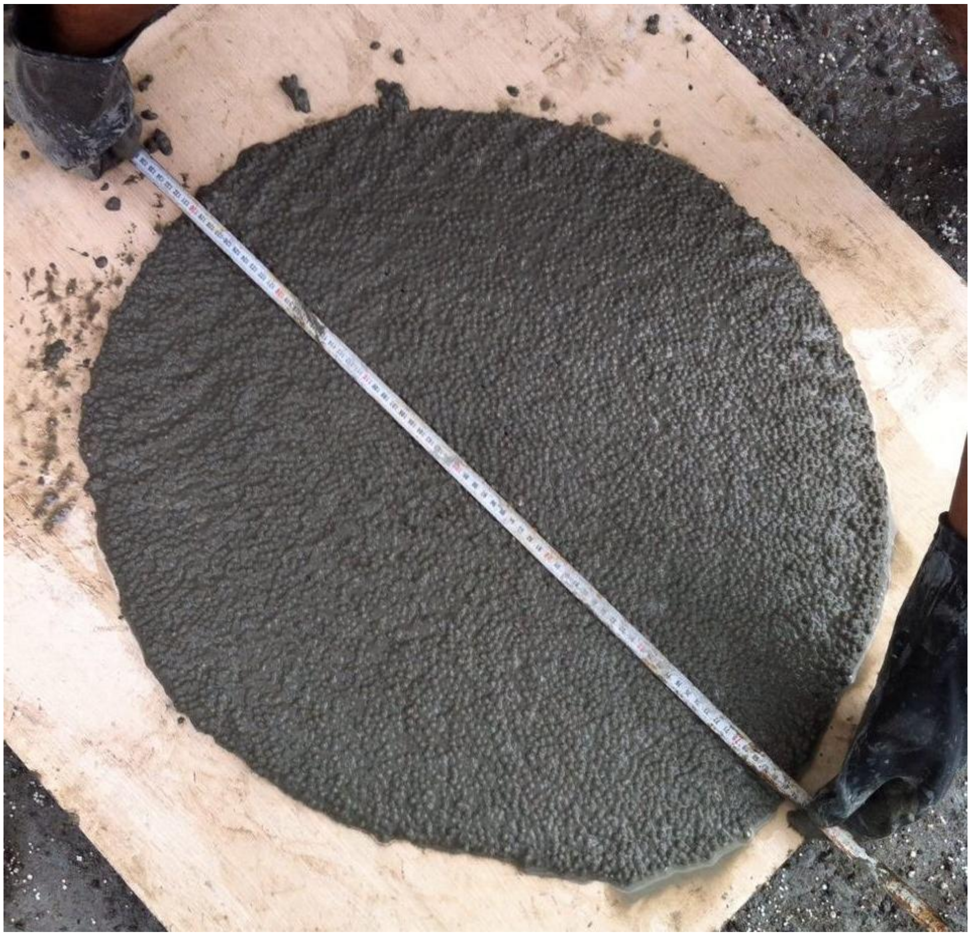

Figure 2: Slump test on the concrete containing coarse EPS

As it is clear from the figure, any heaving, or detachment is not seen in the mix that this is due to accurate use of super-lubricant. It is noteworthy that the self-compacted concrete owes its rheological properties to the super-lubricant, but the accurate regulation of the super-lubricant is very sensitive and even with the addition of small amounts of super-lubricant, the concrete may detached that is not returnable. However, in self-compacted concrete containing EPS this issue is more difficult because these grains are highly vulnerable to heaving because of the fluidity of the mix and also low density that with a little fluidity more than the required amount of the mix, these seeds come to the surface of mix and the concrete mix is entirely destroyed. In Figures 3 and 4, two pictures of V-funnel test are seen over this concrete.

Figure 3: The area of funnel

Figure 4: The discharge of funnel

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As it is seen in Figure 3, EPS seeds after entering into the funnel chamber also have been heaved, which this issue owes a good amount of super-lubricant and silica fume that cause the proper adhesion between the mixture of cement and EPS aggregates. In Figure 4, we also see the mix after discharge from the funnel that is still without separation, bleeding and heaving, which is excellent. It is noteworthy that existence of EPS seeds in the surface with large quantities is not due to heaving but it is because of too much amount of the light weight aggregate in the design.

After performing self-compaction tests, the used concrete was poured into cube frames in order to be used to measure the density of concrete after hardening. After 24 hours, the frames were opened and then the averaging of the weights of 10specimens for each design, the mix density was calculated in terms of kg/m^3, which is shown in Table 5.

Table 5: Density of the concrete

No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Project's name	E0	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12
Average density	2350	1904	1965	1826	1945	1648	1686	1555	1660	1295	1446	1147	**1325**

As the above table shows, in all cases in constant replacement, designs containing fine EPS have the minimum density and designs containing combined EPS have maximum density. Also in general and in equivalent by increasing the replacement percentage of EPS we witness the reduction of concrete density.

After opening the frames, in order to obtain the density of concrete, some specimens were cut to investigate the distribution of EPS at the height of the specimens. In Figure 5, the cross-cut of three specimens is observed.

Figure 5: The cross-cut

As seen in the figure above, the distribution of the light weight aggregate is uniform at entire height of the cross-section, which this indicates the high adhesion of these particles with cement past eat the presence of silica fume. In the E7 design (middle sample), the reason of low space being surrounded by EPS is the existence of higher volume of gravel.

Conclusion

1. Despite the high fluidity of self-compacted concrete, still it can be applied using an appropriate mix design of EPS as light weight aggregate in this type of concrete.
2. The use of stone powder to increase the viscosity of concrete, and the use of silica fume to increase the adhesion of cement mix and EPS light weight aggregate in self-compacted concrete is necessary and without these two materials the construction of self-compacted concrete with this light weight aggregate is virtually impossible.
3. Replacing a size of EPS with an aggregate especially fine aggregate heavily affects the properties of self-compaction and causes detachment and heaving.
4. The best case for construction of self-compacted concrete with EPS in conditions that not heaving is happened and also the self-compaction condition is satisfied is the use of all 3 sizes of EPS in concrete mix.
5. In general, after the combined designs, the best case of self-compaction is related to coarse EPS and by becoming smaller the size of seeds, the self-compaction properties in concrete is decreased. It is noteworthy that the smaller grains replace the sand which is the basic element of self-compacted concrete; therefore, their negative impact on the self-compaction properties have been intensified.
6. It should be noted that the water makes fluid the concrete mix, but causes detachment. The supper-lubricant gives the mix a plastic state that in addition to high fluidity has high adhesion. Therefore, in construction of the self-compacted concrete especially with EPS light weight aggregate, it is strictly recommended the amount of water to be controlled and if possible a low amount of water ultimately up to 0.35 (of the volume of mix) is used.

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