

In vitro evaluation of additives allowed for high strength concrete (HSC) and foam concrete

Yüksek mukavemetli beton (HSC) ve köpük beton için izin verilen katkıların in vitro değerlendirilmesi

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Abstract

Thanks to significant advances in materials science, researchers have managed to fabricate and develop different types of concrete proportional to application of new concrete technologies, such as high strength concrete (HSC) and foam concrete. The current paper presents the results of in experimental studies on foam concrete and its application. In addition, the effect of various parameters such as cement content, Water/Cement ratio as well as application of additives has been studied in mix design. In HSC, interaction between concrete constituent materials plays an important role in mechanical properties and compressive strength of concrete. Therefore, an appropriate understanding of these factors helps us select the suitable type and amount of materials in order to make a concrete with desirable behavior and strength. The methods and theoretical procedures used in the study is based on the ACI codes. This study aims to investigate the effect of using Micro Silica and plasticizer on strength of HSC. Based on the obtained results, the optimum percentage used for concrete mix design and positive effects of these materials on concrete property were confirmed.

Keywords: Foam concrete, HSC, Micro silica, Plasticizer, Fly ash, Compressive strength

Öz

Malzeme bilimindeki önemli ilerlemeler sayesinde araştırmacılar, yüksek mukavemetli beton (HSC) ve köpük beton gibi yeni beton teknolojilerinin uygulanmasına orantılı olarak farklı beton tipleri üretilip geliştirmeyi başardılar. Bu yazıda köpük beton ve uygulamaları üzerine deneysel çalışmaların sonuçları sunulmaktadır. Ayrıca çimento içeriği, su / çimento oranı ve katkı maddeleri gibi çeşitli parametrelerin etkisi karışım tasarımında incelenmiştir. HSC'de beton kurucu maddeler arasındaki etkileşim, betonun mekanik özelliklerinde ve basınç dayanımında önemli rol oynamaktadır. Bu nedenle, bu faktörlerin uygun bir şekilde anlaşılması, istenen davranış ve dayanıklılığı olan bir betonun yapılması için uygun tür ve miktarda malzemeyi seçmemize yardımcı olur. Çalışmada kullanılan yöntemler ve teorik prosedürler ACI kodlarına dayanmaktadır. Bu çalışma, HSC'nin mukavemetine Micro Silica ve plastikleştiricilerin kullanılmasının etkisini araştırmayı amaçlamaktadır. Elde edilen sonuçlara göre, beton karışımı tasarımı için kullanılan optimum oran ve bu malzemelerin beton mülkiyet üzerindeki olumlu etkileri doğrulanmıştır.

Anahtar kelimeler: Köpük beton, HSC, Mikro silika, Plastifiyan, Uçucu kül, Basınç mukavemeti

1 Introduction

In today's advanced world and with respect to advances in various fields, concrete industry has also undergone major improvements including production of foam concrete which reduces the dead load of a concrete structure, mitigates earthquake-induced force to the structure and leads to lower debris weight after structure collapse [1]-[3]. Based on its specific properties, foam concrete has different applications distinguished in terms of its special weight and compressive strength [4]. Lightweight aerated concrete became popular in the US, Netherlands and later in Germany since 1923. Today, application of light weight concrete (foam concrete) has become popular across different countries as a light and cost-effective material [5]. However, using of the lightweight concrete has been used in the seismic regions if their seismic code has been recommended that it can be used. Arman et al. [6], conducted a comprehensive study on effective parameters and properties in foam concrete (such as high strength-to-weight ratio and low density); moreover, they presented a comprehensive view about possible equipment to produce foam concrete in industry. Jiang et al. [7] conducted a study on high-porosity foamed concretes made by ordinary Portland cement. In their study, they examined all the effective parameters in such concretes and determined optimum value

of each parameter. Guo et al. [8], performed a theoretical and experimental study on non-linear, mechanical response of foamed concrete under non-axial compressive load over a wide range of temperatures and strain rates. They concluded that non-linear deformation behavior of foamed concrete undergoes various changes relative to changes in density and temperature.

The current research presents an experimental study in production of foam concrete, whereby ideal percentages for mix design of this concrete type are introduced; in addition, "do's and don'ts" to produce a high-quality foam concrete are presented based on the experimental results.

Nowadays, along with the progress in construction industry, the importance of High Strength Concretes (HSC) is more evident than before. Mousa [9] conducted an experimental program in order to investigate the flexural behaviour of concrete beams (HSC) with variable length of tension reinforcement lap splice. Results show that by introducing an appropriate amount and distribution of transverse reinforcement, a satisfactory ductility response can be obtained. EL-Azab and Mohamed [10], examined the effect of tension lap splice on the behavior of high strength concrete (HSC) beams. The research involved tests on sixteen simply-supported beams of 1800 mm span, 200 mm width and 400

mm thickness made of HSC. Finally, properties like failure load, cracking load, crack propagation, crack pattern, and midspan deflection were examined and compared. Grygo and Lapko [11], presented a study on HSC made of recycled aggregate

concrete. The results were either experimental or non-experimental showing many positive effects like higher flexural capacity and stiffness under short time loading. Due to advances in technology and the use of HSC, deformation criterion in structural design and the strength of the materials used will not be the only criteria of structural design and other considerations such as elastic stiffness should be taken into account [12]. Importantly, it is impossible to obtain such strength without using special additives and smart concrete mix design. This research aims to experimentally examine the importance of using these additives. Experimental results show importance of materials type, their properties and their ratio in each concrete mix design in order to have a high quality concrete.

2 High strength concrete (HSC)

This study tries to achieve a concrete with compressive strength of 60 MPa and examines the effect of Micro Silica and plasticizer on it. For this purpose, 5 types of mix designs are predicted for each of which 6 concrete samples were considered in order to minimize experimental errors and use the average data.

2.1 Concrete mix designs with compress length of 60 Mpa

Concrete mix design is prepared based on Codes ACI 211 and ACI 363 [13],[14] with the following considerations and experimental conditions (see Table1):

Table 1: Type of material used in the study.

Type of Material	Material Properties
28-day compressive strength of concrete	60 MPa
Type of cement	Portland cement type II with specific mass of 3.15 gr/cm ³ , compressive strength of 250 kg/cm ² and chemical composition of 2.04, 4.95, 21.25 and 64.07 for SO ₃ , Al ₂ O ₃ , SiO ₂ and CaO, respectively
Density of cement	3150 kg/m ³
Density of sand	2300-2400 kg/m ³
Density of gravel	2600-2500 kg/m ³
Moisture content of fine and coarse aggregate	5 and 1 (respectively)
Maximum aggregate diameter	20 mm;
Degree of workability	Very Low
Type of used micro silica	The Micro Silica used is in the form of hydraulic powder composed of SiO ₂ particles in bright gray color (Figure 1)
Compacting factor	very low (0.85)
The plasticizer used	This material is made on PCU basis. It is brown with specific density of 1.1 kg/cm ³

The mix design of interest is performed using a series of experimental graphs known as Erntropy and Shaklock in ACI 363 codes, as follows:



Figure 1: Micro silica used in concrete mix design.

2.1.1 Reference number assessment

Supposing that 28-day strength is 600 kg/cm² and with the suppositions mentioned in section 2.1, Reference Number is obtained using the graph in Figure 2.

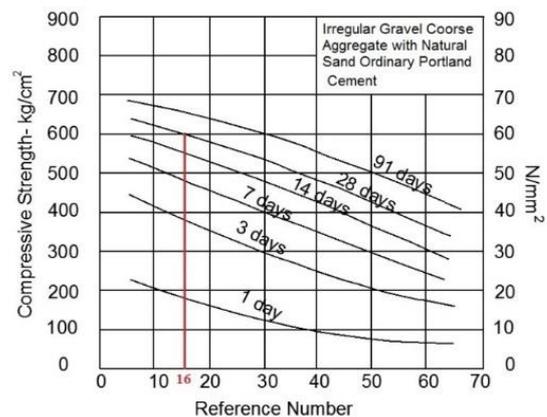


Figure 2: Graph of obtaining reference number [14]. According to graph in Figure 2, Reference Number is equal to 16.

2.1.2 Water/Cement ratio (W/C) assessment

According to the value of Reference Number obtained in 2.1.1 and maximum aggregate diameter of 20 mm and considering the degree of workability to be Very Low, W/C Ratio will be 0.331 (Figure 3).

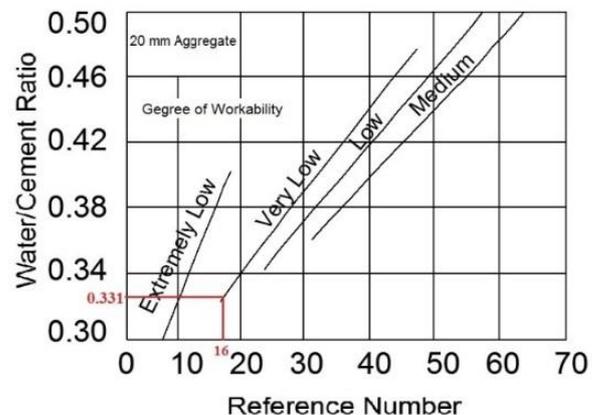


Figure 3: Relation between water/cement ratio and reference number for 200 mm maximum size aggregates [14].

2.1.3 Aggregate/Cement ratio (A/C) assesment

The A/C Ratio is obtained based on ACI 363 code. To obtain A/C ratio in this Table, the following parameters, obtained in previous steps, are necessary:

- Aggregate material: Irregular Gravel;
- Maximum aggregate diameter: 20 mm;
- Degree of Workability: Very Low;
- Water/Cement Ratio: 0.331.

As a result, A/C Ratio will be 2.9 based on the Table.

2.1.4 Weight ratio of each aggregate

The aggregates are combined using the graphical method shown in Figure 4, such that 30% of aggregates pass through 4.75 mm IS Sieve.

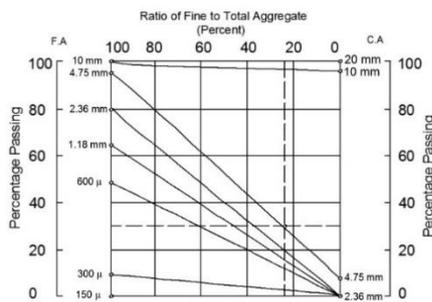


Figure 4: Combining coarse aggregate (C.A) and fine aggregate (F.A).

According to the graph shown in Figure 4 and the existing condition of materials, the weight ratio of each aggregate can be obtained as follows:

C.A/Cement Ratio: 3.15,

F.A/ Cement Ratio: 1.05,

The required ratios are obtained based on dry weight of materials. As a result, concrete mix design of interest is obtained as shown in Table 2. Compressive strength test of the first sample has been shown in the Figure 5.

Table 2: Concrete mix design of interest.

Weight of material	In 1 m ³ of concrete	In 50 cm ³ of concrete	In 60 cm ³ of concrete
Type of material	(kg)	(kg)	(kg)
Cement	419.3	8.95	10.75
Sand	440.2	9.40	11.28
Gravel	1320.7	28.20	33.83
Water	161.4	3.45	4.13
Total weight	2341.6	-	-

2.2 Experimental results of samples

In this study, 5 types of mix designs are predicted and 6 concrete samples are considered for each of them in order to minimize the experimental errors and use the average data. In the first mix design, the sample is considered with no additives in order to compare the effect of additives in other samples.

When the first sample faced failure; that is, mix design of the first sample could not reach the compressive strength and since the created concrete of this sample was dry and far lower than the required amount in terms of degree of workability, it was concluded that water/cement ratio should

be experimentally increased in mix design of the second sample (up to 0.5) to make it compressible and reach the desired degree of workability. However, an increase in water/cement ratio decreases concrete compressive strength [15]. When no results were obtained in the second sample, based on the mix design of the first sample, plasticizer and Micro Silica described in section 2.1 were added to samples 3-5 and the results were collected. In the third sample, plasticizer with no Micro Silica was used. Finally, in samples 4-5, plasticizer with a fixed dose was used by adding Micro Silica with a changing dose. The amount of adding plasticizer should be in terms of a percentage of cement weight and is added to mix design water; the amount of adding Micro Silica should be in terms of cement weight and then combined with cement [16]. Results of all mix designs are presented in Table 3.



Figure 5: Compressive strength test of the first sample.

3 Foam concrete

Concrete is basically a mixture of two components: Aggregates and paste. Light making can be done in both components and has special properties in each part and is performed using different techniques [17].

3.1 Lightweight cement paste production

Materials involved in lightweight concrete combination include: cement, sand, lime (depending on the type of foam concrete), entraining materials, water and additives such as Micro Silica, super plasticizers, fly ash, Polypropylene fibers, Plone, etc. However, some types of entraining materials are applicable in lowering concrete water absorption. Chemical entraining or foaming agents are non-recyclable and chloride is used to ensure their stability; notably, chloride can also cause corrosion in contact with steel; therefore, entraining agents containing chloride should not be used in RC and the concrete produced with these materials has no structural application [17].

Table 3: Results of compressive strength test of samples.

NO.	Weight of gravel (kg)	Weight of sand (kg)	Weight of water (kg)	Weight of cement (kg)	Percentage of Plasticizer to cement	Percentage of Micro Silica to cement	7-day compressive strength (MPa)	28-day compressive strength (MPa)	Specific density of concrete (Kg/cm ³)
1 st	1320.7	440.2	161.4	419.3	-	-	32.4	42.11	2456
2 nd	1320.7	440.2	188.6	419.3	-	-	31.8	35.03	2445
3 rd	1320.7	440.2	161.4	419.3	1.0	-	48.4	62.92	2527
4 th	1320.7	440.2	161.4	419.3	1.0	10.0	51.6	72.20	2422.5
5 th	1320.7	440.2	161.4	419.3	1.0	15.0	39.5	55.30	2502

The concrete produced in this way has the following features [18]:

- Reducing specific weight;
- Reducing concrete production cost;
- Increasing concrete slump thereby decreasing W/C Ratio of mix design;
- The possibility of properly forming the concrete surface;
- Easy concrete pumping for story buildings;
- Good frost resistance.

The lightweight concrete produced by this method (foam or aerated concrete), with respect to cement paste porosity and its low strength which leads to decreased strength of the produced concrete, has fewer structural applications and is more used in producing materials with lower loading rates [18].

3.2 Application of lightweight aggregates

Lightweight aggregates are aggregates with inner porous space. Some of the lightweight aggregates that are used to produce lightweight concrete are available naturally while others are produced artificially. As the natural aggregates Pumice, Vermiculite and volcanic ash can be mentioned. Artificial aggregates are being made from heating and expansion of materials such as clay. However, Silica-based, fly ash-based, etc. lightweight aggregates are also available which are less applicable than clay lightweight aggregates with respect to the type of raw materials and production method [17]. Due to their specific production condition, lightweight aggregates of this type have special advantages in addition to being light including:

- As an industrial product, it delivers suitable consistent quality,
- It has no mineral limitation like natural lightweight aggregates,
- It lacks harmful materials which may exist in natural lightweight aggregates; its pH is normal about 7.2,
- It lacks harmful organic matters because it is exposed to more than 1200 °C temperature; therefore, it has good thermal shock resistance [17],[19].

The concrete produced by this method can have structural application; for this purpose, high-strength cement paste

should be used; therefore, Micro Silica and a combination of aggregates and lightweight aggregates are used in order to produce this type of lightweight concrete [16].

3.3 Description of materials and the performed experiments

The experiment was performed with different densities in order to determine mechanical and physical properties of foam concretes. The properties of interest including dry and wet specific weight, water absorption, drying-induced shrinkage, and compressive strength are calculated.

3.3.1 Description of used materials

- Cement: type II Portland cement,
- Gravel: very small gravel was used in this study,
- Foaming material and foam stabilizer: the foaming material and foam stabilizer were diluted with water with 1:5 ratio.

3.4 Foam concrete mix design

Foam concrete mix design was decided based on absolute volume of raw materials for each density. The volume of water hydration was considered as a percentage of cement amount. The amount of cement corresponds to the range recommended in [16]; The cement weight in mix was determined by subtracting cement weight and hydration water from dry density. Through calculating the amount of water mix in order to achieve the desired uniformity as well as cement and gravel density in mix, air-voids and foam volume requirements are determined. In order to examine the effect of various parameters on foam concrete properties, a series of experiments was conducted in this study. The raw material mixture for the production of foam concrete containing cement, water, foam and aggregate (fly gravel, stone powder, etc.) are used in mix design with different amounts in order to achieve volumetric weight and other required specifications. Foam is a protein-based or chemical material with stable foaming property. Stability means that foam maintains its property during mixture and dislocation process and until the initial cementing process thereby leading to formation of pore space inside concrete [16]. The produced foam has been shown in the Figure 6.



Figure 6: The produced foam.

Chemical foaming agents have lower stability used to produce concretes with higher volumetric weight as well as structural concretes. Moreover, chemical foaming agent has lower durability than the preprotein type. The protein-based foam has a more suitable foam durability and quality; however, long-term preservation of its raw materials is impossible. The base material is diluted with water (the mix ratio of foam liquid to water was 1:5) and it is poured in the foam maker machine. In order to produce stable foam. The final product- the foam of interest- should be added to concrete mixture. The most suitable method of mixing foam with concrete is to first make the base concrete containing cement, water and gravel and then add the foaming agent [17].

Table 4: Specifications of three types of foam available in the workshop.

Foam stability (min.)	density ($\frac{kg}{m^3}$)	Type of foam
60	72	Protein-based foam
30	48	Chemical foaming agent-Type I
40	40	Chemical foaming agent-Type II

In this research, the chemical foaming agent- type II is used to make the laboratory samples.

Table 5: Specifications of the materials used in concrete mix design.

density (kg/m^3)	Materials
3150	Cement
2520	gravel (fly)
2090	Fly ash
2100	Stone powder
40	Foam

In order to perform the experiment, concrete samples of $15 \times 15 \times 15 \text{ cm}^3$ dimensions were used, as shown in Figure (7).

3.5 Water/Cement and gravel ratios in foam concrete specifications

3.5.1 Water/Cement ratio assesment

In general, the amount of water used in this concrete is high and the W/C ratio ranges between 0.4-0.7 [17], which is because this concrete contains a high percentage of fine aggregates which increases the amount of water consumption in the mix design. If water content in the mix design is considered to be low, the mixture compensates for its water shortage with the foam, thereby the foam is lost and volumetric weight of concrete increases. Moreover, it should be noted that high percentage of water consumption in the

mix design increases concrete shrinkage. In other words, it is very important to control the content of water consumption in foam concrete mix design.

3.5.2 Gravel/Cement Ratio Assesment

Generally, only cement and no gravel is used in the mix design in order to obtain low densities of about 300 kg/m^3 . For achieving higher densities as well as higher compressive strength, the gravel/cement ratio is increased. Generally, 1, 0.5 and 1.3 ratios (cement/gravel) are used [17]. Cement content used is not lower than 300 kg/m^3 since it leads to sharp drop in the strength. In order to examine the effect of used materials on characteristics of foam concrete, the following experiments were performed by replacing stone powder, fly gravel, fly ash in the mix design.



Figure 7: The produced foam concrete samples.

Table 6: The initial mix design of samples for the foam concrete.

Sample	Specific weight of concrete (kg/m ³)	Foam (m ³)	Water (kg)	Fly ash (kg)	Stone powder (kg)	Fly gravel (kg)	Cement (kg)
1 st	620	0.5	280	370	400	340	170
2 nd	352	0.5	280	300	340	280	170
3 rd	690	0.5	280	340	420	300	170

Table 7: Mix design in order to improve the strength of samples.

NO	28-day strength (kg/cm ²)	Specific weight (kg/m ³)	Foam (m ³)	Water (kg)	Fly ash (kg)	Stone powder (kg)	Fly gravel (kg)	Cement (kg)
1 st	153	1340	0/2	400	500	800	600	300
2 nd	84	1150	0/2	400	400	600	500	300
3 rd	73	1410	0/2	400	600	700	700	300

3.6 A discussion of experimental results

Shrinkage due to drying of mixtures was determined in form of 15×15×15 cm³. The samples were transferred to normal laboratory condition with relative moisture of 40% after 28 days of moisturizing. As a matter of fact, some studies conducted on foam concrete [18],[19] restrict the consumption of this material to cases that high shrinkage is not problematic. In coastal areas with no access to clay resources for construction of clay bricks and blocks, transportation costs increase the price of brick and block by-products by 100% [20- 23]. However, fly gravel resources abound in these areas, where concrete blocks and panels can be made in these regions using foam concrete which is cost-efficient. They can also be used in place of aggregated materials for excavation filling in the streets. The former advantage guarantees foam concrete performance in case of its application in sub base level of ways, particularly in regions with no access to suitable aggregated material resource. In addition to the above advantages, with respect to fire resistant property of this type of concrete, it can be used as a fireproof material.

4 Conclusion

The experimental results concerning high-strength concrete (HSC) are as follows:

- In order to increase HSC plasticizer ability, no water can be used; since it highly decreases compressive strength of concrete (compared to the compressive strength of the 1st and 2nd samples),
- Micro Silica has a positive effect on increasing the compressive strength of concrete. Micro Silica particles contribute to reduction in pore space within concrete aggregates due to their very small diameter, by doing so, they contribute to an increase in the compressive strength of concrete in addition to making the concrete impermeable (compared to the 3rd and 4th samples),
- In case of using Micro Silica in HSC, super plasticizer should be added to the concrete, because Micro Silica decreases concrete consistency due to its extremely fine particles; since the W/C ratio cannot be increased in order to increase efficiency, plasticizer

should be added to increase the degree of workability,

- The dosage of Micro Silica is 10% of cement weight; as this dosage increases, the strength decreases since cement paste is not properly bonded to the aggregate (comparing the 4th and 5th samples). However, this dosage depends on the Micro Silica manufacturers.

Experimental results about foam concrete:

Compressive strength of foam concrete mixtures is highly influenced by Water/Cement ratio contents. Mixtures with lower water/cement ratio have higher strength in similar densities. Application of coarse gravel, particularly in heavier mixtures, leads to a significant reduction in water/cement ratio. A more suitable performance of these mixtures results in higher compressive strength. Notably, the foam added to the mixtures depends on the consumed volume of foam and its density. Shrinkage due to drying is determined by measuring length of samples at various time intervals. High drying shrinkage of foam concrete is an important aspect which should be taken into account in application of this material.

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