

# The Influence of the Types of Iraqi Sands on the Physical and Mechanical Properties of Foamed Concrete

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## ABSTRACT

Recently, the use of foamed concrete has expanded significantly in Iraq due to its properties and the availability of raw materials. Since fine aggregate (sand) is one of the basic elements in the production of foamed concrete, it plays an important role in determining its properties. This study examined three types of sand (S1, S2, S3), distributed across three governorates (Karbala, Salah al-Din, and Anbar), respectively. Numerous rigorous tests were conducted on this sand to determine its physical and chemical properties. The results showed a significant improvement in the physical properties of the concrete during the test period, related to the dry density and porosity, which are related to the speed of transmission of ultrasonic waves through the concrete medium. There was also a significant improvement in mechanical properties, including compressive, tensile, and flexural strengths during the test. The results also indicate that the best type of sand was Anbar sand (S3) used in the MS3 concrete mix.

*Keywords-Foam Concrete (FC); type of sand; physical properties; mechanical properties*

## I. INTRODUCTION

As a result of developments in the construction sector in recent years, many concrete materials have been discovered and developed. Among them, Foam Concrete (FC) has received particular attention due to its unique and distinctive properties [1, 2]. FC, also known as cellular concrete, is a cement mortar that contains air spaces within it, giving it numerous properties, such as lightweight, thermal and sound insulation, and environmental friendliness [3]. FC is made by mixing cement with sand to form a cement mortar. Pre-prepared foam is then incorporated into the mixture to form FC with a closed-pore system [4].

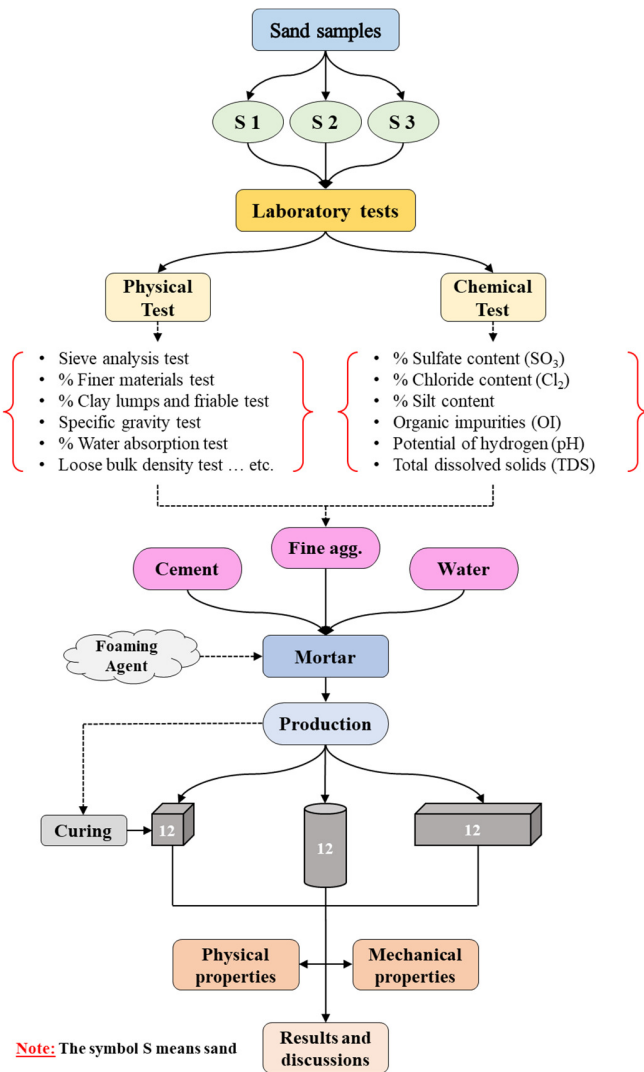
FC can be produced in various densities ranging from 300 to 1800 kg/cm<sup>3</sup> [5, 6]. Its compressive strength ranges from 0.2 to 10 MPa, making it suitable for a variety of non-structural purposes, such as flooring, filling wall joints, and leveling surfaces. Its strength can be increased by adding other materials, such as silica, which improves its density and strength, and fibers, which increase its tensile strength. This allows it to be used for specific construction purposes [5, 7]. The materials used in the production of FC play an important role in determining its properties [8].

In [9], fly ash was used at 25, 50, and 75% of the cement weight to produce 20 concrete mixtures with densities ranging from 800 to 1600 kg/m<sup>3</sup>. The results of this study showed that increasing fly ash improves workability and reduces strength. Previous studies also demonstrated the production of FC with a homogeneous structure and good physical and mechanical properties as a result of using fine silica-rich sand [10]. In [11], FC with good mechanical properties and durability was produced as a result of using 50% quartz sand in its production. In [12], sustainable LWFC was produced using limestone dust and silica fume in two stages. First, limestone dust was used as a partial cement replacement at 10, 14, and 18% by weight to determine the optimal foaming agent dosage. Chemical analysis showed similarity between cement and limestone dust, in addition to an improvement in compressive strength during the test ages. However, strength decreased when using 14% limestone dust due to its lower dry density. Second, adding polypropylene fibers at 1, 1.5, and 2% by volume, with 14% of limestone dust, resulted in an improvement in the flexural and splitting tensile strengths at 28 days.

This study focuses on evaluating the effect of using Iraqi sand with different properties on the physical and mechanical properties of FC.

II. METHODOLOGY

Figure 1 illustrates the method followed in this study.



Note: The symbol S means sand

Fig. 1. Study flowchart..

III. EXPERIMENTAL WORK

This section describes the materials used in the production of FC and their properties, as well as the mixing, casting, and curing methods.

A. Materials

1) Cement

Cement is the binding material in the FC mixture. Ordinary Portland Cement (OPC) (CEM I – 42.5 R), conforming to IQS No. 5/2019 [13], was used. Tables I and II show the physical properties and chemical composition of the cement, respectively.

TABLE I. PHYSICAL PROPERTIES OF OPC

Properties	Test Result	Limitation
Fineness (Blaine method) (m <sup>2</sup> /Kg)	390.2	≥ 280
Time of setting (Vicat test):		
Initial set (hrs:min)	02 : 10	00 : 45 (min)
Final set (hrs:min)	04 : 20	10 : 00 (max)
Compressive strength (MPa):		
2 Days	25.55	≥ 20 MPa
28 Days	45.48	≥ 42.5 MPa

TABLE II. CHEMICAL COMPOSITION OF OPC

Oxide Compositions	Test Result	Limitation
Lime (CaO)	63.29	---
Iron oxide (Fe <sub>2</sub> O <sub>3</sub> )	4.12	---
Alumina (Al <sub>2</sub> O <sub>3</sub> )	5.25	---
Silica (SiO <sub>2</sub> )	19.88	---
Insoluble residue (IR)	0.62	The max (1.5)
Magnesia (MgO)	2.78	The max (5)
Loss on ignition (L.O.N)	2.68	The max (4)
Sulfate (SO <sub>3</sub> )	2.45	SO <sub>3</sub> ≤ 2.8 if C <sub>3</sub> A > 3.5
<b>Main Cement Compounds<sup>a</sup></b>		
Tri-calcium Silicate (C <sub>3</sub> S)	58.35	---
Di-calcium Silicate (C <sub>2</sub> S)	13.06	---
Tri-calcium Aluminate (C <sub>3</sub> A)	6.95	---
Tetra-calcium Aluminate-Ferrite (C <sub>4</sub> AF)	12.52	---

a. Bogues' equations calculate the percentages of major compounds.  
 b. The chemical composition and physical properties of cement were examined in the Iraqi standardization and quality control system.

2) Fine Aggregates (Sand)

Iraq has numerous sand quarries with varying properties. This study used three types of Iraqi sand, S1, S2, and S3 (see Figure 2), distributed across three governorates: Karbala, Salah al-Din, and Anbar, respectively.

The physical and chemical tests of the sand were carried out following the IQS No. 45/1980 [14], and the results are shown in Tables III and IV.

TABLE III. PHYSICAL PROPERTIES OF SAND

Properties	S1	S2	S3
Silicon dioxide (SiO <sub>2</sub> ), %	78.53	59.78	70.25
Materials finer than No. 200sieve, %	1.2	4.5	1.9
% Clay lumps & friable	0.57	4.5	0.93
Fineness modulus (FM)	3.11	2.47	2.54
Relative density (OD)	2.53	2.33	2.57
Relative density (SSD)	2.57	2.39	2.59
Apparent relative density (SSD)	2.64	2.48	2.62
Density (OD) (kg/m <sup>3</sup> )	2520	2323	2564
Density (SSD) (kg/m <sup>3</sup> )	2563	2383	2584
Apparent density (SSD)	2634	2471	2617
Water absorption, %	1.71	2.56	0.79
Loose bulk density (kg/m <sup>3</sup> )	1403	1332	1535
Rodded bulk density (kg/m <sup>3</sup> )	1509	1505	1653
Voids for loose density, %	44.4	42.7	40.2
Voids for rodded density, %	40.1	35.2	35.6

TABLE IV. CHEMICAL PROPERTIES OF SAND

The Properties	S1	S2	S3
Sulfate content (SO <sub>3</sub> ), %	2.976	2.086	0.038
Chloride content (Cl <sub>2</sub> ), %	0.007	0.006	0.007
Silt content, %	8.51	18.92	9.43
Organic Impurities (OI)	2 G <sup>a</sup>	0 G	2 G

a. G means of grade.

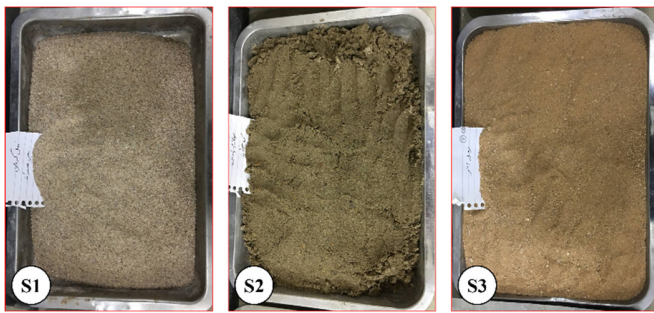


Fig. 2. Types of sand.

Table V shows the general external properties of sand, including texture, particle shape, size, and fineness. The maximum particle size of sand used in foamed concrete production is 1.18 mm. Large particles were eliminated because they cause air bubbles to break during mixing [15]. Figure 3 shows the sieve analysis of the samples.

TABLE V. GENERAL EXTERNAL PROPERTIES OF SAND

Properties	S1	S2	S3
Surface texture	R	S & F	F
Grain shape	Ir.	Ro.	Ir.
Fineness	Coarse	Fine	Fine
Particle size distribution	A	B	C

a. R: Rough, S: Smooth, F: Fine, Ir.: Irregular, Ro.: Rounded, A: Continuous, very tight, B: Continuous, more or less spread out, C: Continuous, spread out.

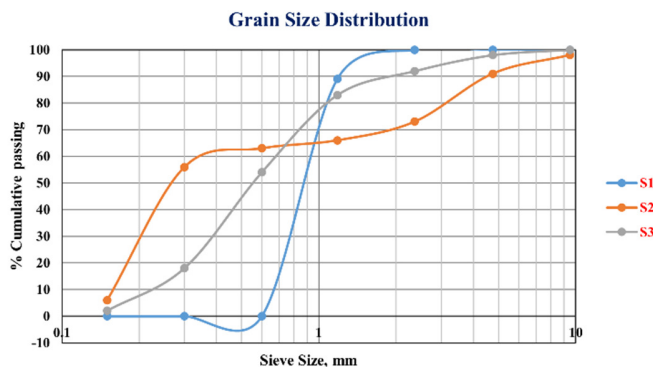


Fig. 3. Sieve analysis of sand.

3) Foaming Agent

A protein-based foaming agent (PA-1) was used. The foaming agent was diluted with water at a ratio of 1:30 and treated using a foam generator to produce a stable foam with a density of (65-68) kg/m<sup>3</sup>. The resulting foam complies with the requirements of ASTM C796-97 [16]. Table VI shows the properties of the foaming agent.

TABLE VI. PROPERTIES OF THE FOAMING AGENT (PA-1)

The Properties	Limits
Foaming agent appearance	Dark brown coloured
Specific density agent	1.1
Dilution (premix)	1:30
Expansion rate	(12 – 15) times
Aqueous foam appearance	Cream colored
Aqueous foam density	(65-68) kg/m <sup>3</sup>
Shelf life	(12-18) months

4) Mixing Water

Potable tap water, complying with IQS No. 1703/2018 [17], was used for mixing and curing all foamed concrete mixes.

B. Mixture Procedure of Foamed Concrete

The mixing process was carried out using a 500-liter mixer equipped with modified blades to ensure even foam distribution. The mixing process followed [18]. Sand was added to the mixer with 10% mixing water to moisten it and mixed for 30 seconds. Cement was then added, and mixing continued for 1 minute to ensure homogeneity. The remaining water was gradually added, and mixing continued for 1 minute until a homogeneous cement paste with the desired consistency was formed.

The consistency of the paste was verified using the Brewer test [15]. This method uses a hollow cylinder (dimensions of 152.4 mm height and 76.2 mm diameter) placed on a square plate. Finally, the pre-formed foam was gently added to the mortar, with mixing continuing for 1 minute to create FC. Table VII shows the mixing proportions.

TABLE VII. MIXING RATIOS OF FOAMED CONCRETE COMPONENTS

Component	Quantity per (kg/m <sup>3</sup> )
Mix ratio	1:1.3
Target density (kg/m <sup>3</sup> )	900
Obtained density (kg/m <sup>3</sup> )	1000
Cement content (kg/m <sup>3</sup> )	352.1
Sand content (kg/m <sup>3</sup> )	457.6
Designed water (kg/m <sup>3</sup> )	158.4
w/c ratio	0.45
Foam (L)	As needed to reach 1000 (kg/m <sup>3</sup> )

C. Casting

After the mixing process was completed, the FC was poured into special molds coated with a light layer of oil. After the molds were completely filled, the sides were tapped gently to avoid air bubbles collapsing. The molds were covered with a plastic sheet to prevent moisture loss until the samples were extracted 24 hours later (see Figure 4-a).



Fig. 4. Casting and curing models.

#### D. Curing

The samples were extracted and cured by encasing them in a sealed plastic wrap, a method known as sealed curing [19] (see Figure 4-b).

### IV. LABORATORY TEST METHODS

The tests in this study are divided into two sections: the first relates to the physical properties of FC, and the second relates to its mechanical properties.

#### A. Physical Properties

##### 1) Oven-dry Density Test

The dry density of the samples was determined by placing them in an oven for 24 hours at  $105\pm 5^\circ\text{C}$  until the weight was constant. The BS EN 12390-7:2019 [20] was adopted for this process.

##### B. Ultrasonic Pulse Velocity Test (UPV)

UPV testing was conducted on prismatic specimens with dimensions of  $100\times 100\times 400$  mm. The direct method was used during the test, with 5 points per specimen. Specimens were examined at ages of 7, 28, and 56 days. The average of three readings for each age was used. The test was conducted according to BS EN 12504-4:2021 [21].

#### C. Mechanical Properties

##### 1) Compressive Strength Test

Cubic FC specimens with dimensions of  $100\times 100\times 100$  mm were used to determine the compressive strength. A hydraulic device with a capacity of 3000 kN was used at a loading rate of 0.1 MPa/s. Specimens were tested at ages of 7, 28, and 56 days. The average of three readings was calculated for each age. The test was carried out according to BS EN 12390-3:2019 [22].

##### 2) Tensile Splitting Strength Test

The test was carried out on cylindrical specimens with dimensions of  $100\times 200$  mm, using a hydraulic device equipped with a special tool that enables a longitudinal slit to be made along the vertical axis of the specimen. Samples were tested at 7, 28, and 56 days of age. The average of three readings was calculated for each age. The test was carried out according to BS EN 12390-6:2023 [23].

##### 3) Flexural Strength Test

The flexural strength of prismatic specimens measuring  $100\times 100\times 400$  mm was determined using a hydraulic device. The center point loading method was used following BS EN 12390-5:2019 [24]. Specimens were tested at ages of 7, 28, and 56 days. The average of three readings was calculated for each age.

### V. TEST RESULTS AND DISCUSSIONS

#### A. Oven-Dry Density

Figure 5 shows an improvement in the oven-dry density with time, regardless of the type of sand used in the mixture and its unique properties. This increase indicates a decrease in the pore volume in the FC model and, consequently, an increase in its density.

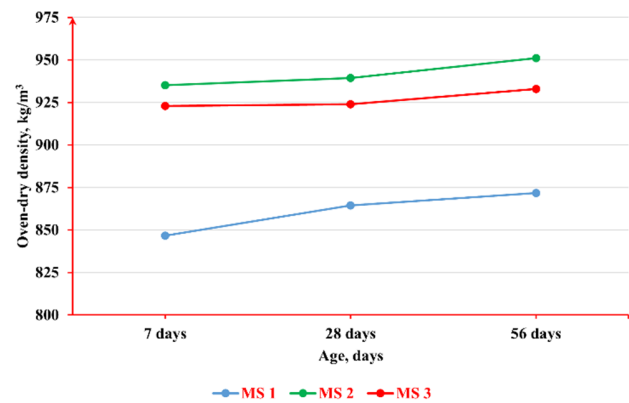


Fig. 5. Oven-dry density results with age.

#### B. Ultrasonic Pulse Velocity (UPV)

From Figure 6, it is clear that the UPV readings gradually improve with the age of the sample due to the decrease in the pore size. The decrease in pore size for some mixes (MS3) is attributed to the pozzolanic activity resulting from the high content of silica oxides in its sand (S3), as these oxides react with calcium hydroxide resulting from the cement hydration process to form C-S-H, which leads to a decrease in the paste pore size.

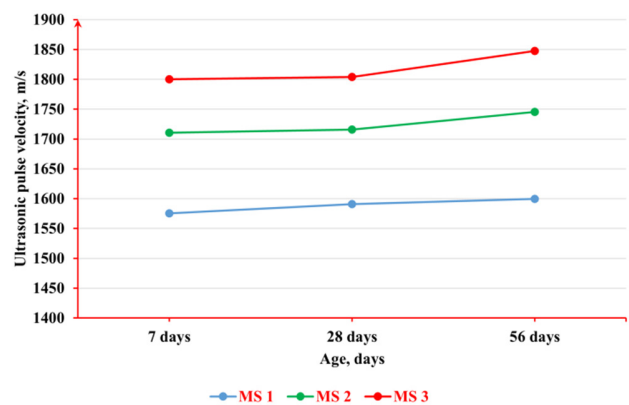


Fig. 6. UPV results with age.

#### C. Compressive Strength

Figure 7 demonstrates the development of the compressive strength of the FC mixes with the age of the specimen. The mixes MS2 and MS3 showed a clear development of compressive strength at the age of 28 compared to the age of 7 days. This development continued until the age of 56 days. The MS3 FC mix was observed to achieve the highest strength improvement of 2.604 MPa. It should be noted that the S3 sand used in the MS3 mix is characterized by several properties, such as its fineness, which increases its density. In addition, it is characterized by its high silica content, which leads to pozzolanic reactions and C-S-H production.

#### D. Tensile Splitting Strength

Similarly to compressive strength, an improvement in the tensile splitting strength of FC can be observed with aging [25]. This improvement is attributed to the pozzolanic interactions of

the silica oxides of the MS3 sample with the calcium hydroxide present in the cement. For MS2, the silt content may play a vital role in filling the pores and increasing the density of the concrete, thus increasing its strength, as shown in Figure 8.

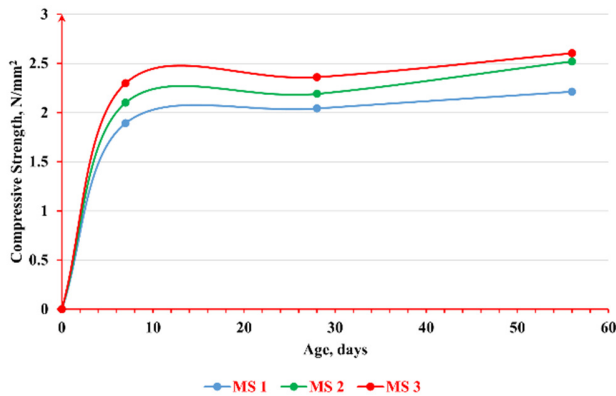


Fig. 7. Development of compressive strength with age.

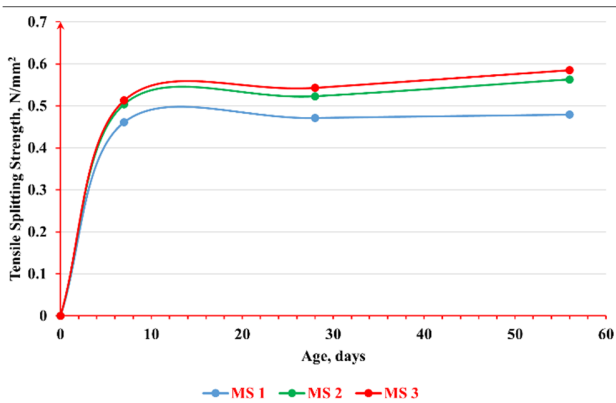


Fig. 8. Tensile splitting strength increases with age.

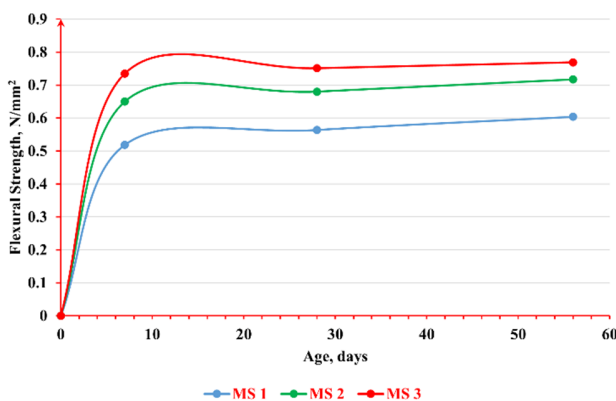


Fig. 9. Flexural strength readings during specimen aging.

### E. Flexural Strength

Figure 9 shows a continuous improvement in strength at the age of 56 days compared to the age of 28. The highest value was 0.769 MPa for the FC mix MS3, followed by the mix MS2 at 0.717 MPa. This improvement is attributed to the shape, texture, and smoothness properties of the S3 and S2 sand types,

in addition to their distinctive physical properties. The pozzolanic reaction between silicon oxide and calcium hydroxide also plays a major role in improving strength, forming a compound called C-S-H, which in turn reduces the porosity of the concrete mixture and increases its density.

## VI. CONCLUSIONS AND RECOMMENDATIONS

Iraq has numerous sand quarries, and their sands vary in their physical and chemical properties. This study used three types of Iraqi sand from different governorates in FC production. Based on the results obtained, the following conclusions can be drawn.

- The physical and chemical properties of the fine aggregate (sand) vary depending on the source from which it was extracted. These differences in aggregate properties can affect the mixing and hardening processes and the properties of the resulting FC.
- The shape, size, and grain distribution of the fine aggregate (sand) influence the physical and mechanical properties of FC. Uniform grain distribution and fineness improve the properties of concrete.
- The silica oxides present in sand S3 have a positive effect on improving the internal structure of the FC model by reducing the pores and making them denser.
- UPV test results indicate that the concrete mix MS3 has a dense structure with small pores, which facilitates wave transmission between pores.
- The compressive strength results show a remarkable improvement, especially for the MS3 FC mix. This is due to the high silica content in its sand (S3), which reacts with calcium hydroxide produced during the cement hydration process to produce C-S-H, which occupies the small voids, increasing the density of the concrete mix. In addition, this type of sand has properties such as increased fineness and specific gravity.
- The tensile and flexural strength properties of concrete mixes are similar to their compressive strength. The mix MS3 achieved the best results with increasing sample age, due to its sand. For mix MS2, the improvement is attributed to the higher clay content, which filled the small voids and increased the density of the mix. Although S1 sand in MS1 has a high silica content, this sand has a uniform gradation (it passes through a 1.18 mm sieve and is retained by a 0.6 mm sieve), resulting in large gaps in the mix, reducing density and durability.

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