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Effect of Finesse and Type of Aggregate on Flowability and Mechanical Properties of Foamed Concrete

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Abstract. This work's goal is to investigate the influence of the type and size of fine aggregate on the characteristics of foamed concrete. Foamed concrete was produced, and its fresh and mechanical characteristics were investigated. It was found that the spread diameter decreased when the foam was added to mixes. With regards to sand grading, when the grading of sand decreased, the diameter of the flow decreased also. Strength improved for fineness sand and enabled the production of uniform and pore distribution, which enhanced the foamed concrete's strength. The increase in compressive strength reflects the other properties of concrete, like tensile strength, that also improved.

Keywords: foamed concrete, silica sand, strength, density, natural size, sieve analysis

1. INTRODUCTION

Foamed concrete is a special type of lightweight concrete with a unit weight of about 300-1800 kg/m^3 and is made by combining cement, fine sand, and water with air bubbles. Components include cement, water, sand, and foam bubbles [1,2]. The amount of foam added to cement paste or mortar can be adjusted to get the desired density. Foamed concrete is created by evenly dispersing air bubbles (foam) throughout the mass of concrete. Components that are essential and optional make foamed concrete. To make cement paste, you need cement, water, and sand. Sand also goes into the mortar, and foam bubbles create foamed concrete [3]. Depending on its density, foam concrete can be used for filling and heat-insulating purposes, semi-structure applications, and structural applications. According to Amran et al. [3], foamed concrete has better qualities, such as a low density that lowers the need for labor, transportation, structural dead loads, and operating expenses. Due to its micro-structural air cells, it also possesses good sound absorption and fire resistance. During mixing, transporting, pumping, and placing steps in concrete manufacturing, the foam cells' walls should remain stable [4]. According to Nambiar and Ramamurthy [5], foamed concrete has gel holes, capillary pores, and air pores, including entrained and trapped ones. To create a homogeneous pore structure, Portland cement paste or mortar can contain entrained air spaces[6].

Foamed concrete offers various benefits, including being lightweight, highly flowable, providing good thermal insulation, and using less aggregate, according to Ramamurthy et al. [7]. According to Jones and McCarthy [8], foamed concrete has a lower strength (compressive and tensile) than normal concrete. According to Nambiar and Ramamurthy [9], foamed concrete shrinks more when drying than normal concrete. Foamed concrete with a unit weight of about 300 to 1000 can be used for heat-insulating purposes kg/m^3, while a unit weight of about 1000 to 1300 kg/m^3 is ideal for semi-structural applications.

The possible use of foamed concrete with uint weight of more than 1300 kg/m^3 for structural applications has finally been the subject of numerous studies [10]. Several densities of foamed concrete have been created to meet building requirements, and these products have been utilized for tunneling, huge blocks, void filling, road sub-base, wall construction, and trench restoration, among other things [10]. Silica sand is usually used to produce reactive powder concrete because of its nature, which improves the properties of concrete [11]. Tariq used silica sand to produce foam concrete and found that it improved its properties a lot [12]. The most obvious benefit of this concrete form is its low density, which always reduces the dead load. Foamed concrete (FC) has cheaper handling and transport costs, excellent thermal insulation qualities, quick construction, and strong sound insulation. They also self-compact and have low thermal conductivity, good flowability, and low density. Cellular concretes are employed in many structural and civil engineering areas because they are simple to produce and inexpensive. Cellular concrete is also used to produce pre-cast panels and lightweight blocks and construct shock-absorbing barriers for airports, road sub-base, and soil stabilizers [13] and [14]. Because of its low density and excellent thermal characteristics, FC is thought to be a useful insulating material during temperature changes, and it is also frequently used under concrete paving to avoid frost heaves beneath pile caps and roads, prevent frost jacking of shallow piles, insulate shoal foundation systems [15].

This study aims to determine whether producing foam concrete using silica sand rather than conventional sand is feasible. Additionally, the impact of sand fineness was also examined. To achieve this goal, foamed concrete mixtures were produced by replacing the natural fine aggregate (sand) once with silica sand and again with normal sand of different fineness. Then, the properties of the foam produced have been evaluated in the fresh and hardened state. Besides, the microstructures were investigated through SEM testing.

2. EXPERIMENTAL PROGRAM

2.1 Materials, Mixing Proportions and Mixing Procedures

The cement that was used satisfied the Iraqi specification IQS 5/2019 [16]. Two types of fine aggregate have been used: natural sand and silica sand. Natural sand was used as fine aggregate in this work. Two groups were used for this sand first, with a maximum size of 2.36 mm, with sieve analysis illustrated in Table 1. The f second group of natural sand has a maximum size of 0.6 mm with sieve analysis illustrated in Table 2. Both used natural sand belong to zone 3 according to IQS 45 / 1986 [17]. Silica sand from a glass factory in AL Ramadi city was used, provided from Ardma land in AL- Anbar province in the west of Iraq. Its particles are angular and rough with a maximum size of 600 microns, with sieve analysis shown in Table 3. Tap water was used for all mixes. A protein foaming agent was utilized to make foamed concrete in this work. The foaming agent solution had a concentration of 25g of foaming agent per liter of water and was used to make foam. The foam was created using a foam generator made locally. To obtain stable foam bubbles, the solution is poured into the tank of the foam generator and compressed with air at roughly 8 N/mm^2. Figure 1, illustrated the materials that have been used in this work.

Table 1: Sieve analysis of natural sand of group 1.

Sieve opening Size (mm)	10.00	4.75	2.36	1.18	0.60	0.30	0.15
passing %	100	100	100	88	70	21	8
I.Q.S. 45/ 1984 [17] [Zone3]	100	85-100	85-100	75-100	60-79	12-40	0-10

Table 2: Sieve analysis of natural sand of group 2.

Sieve opening Size (mm)	10.00	4.75	2.36	1.18	0.60	0.30	0.15
Passing %	100	100	100	100	60	25	3
I.Q.S. 45/ 1984 [17] [Zone3]	100	85-100	85-100	75-100	60-79	12-40	0-10

Table 3: Sieve analysis of silica sand.

Sieve opening Size (mm)	10.00	4.75	2.36	1.18	0.60	0.30
Cumulative passing %	100	100	100	100	48	6

Figure 1: The materials that have been used in this work.

All of the investigated foamed concrete mixes were designed using the absolute volume method at 1700 kg/m^3 density. The amount of cement was fixed (500) kg/m ^{3} [18]. This work implements The absolute volume method for the mixed design of FC. The mixing sequence was achieved by adding half of the sand, and all cement was added, then the residual sand was put in the rotary mixer. After thoroughly mixing the dry materials, the water was gradually added over two minutes [19].

Table 4: Mixes proportions (kg/m^3).

Materials	**Mixes**		
	F2.63NS	**F0.6NS**	**F0.6SS**
C	500.0	500.0	500.0
Sand (kg/m^3)	950	950	-
Water (kg/m^3)	250	250	250
water/cement	0.5	0.5	0.5
Silica sand (kg/m^3)	-	-	950
Foam (liter/m^3)	250	250	250

Where: C: Cement, F: foam, NS: Normal Sand, SS: Silica Sand

2.2 Experimental Tests

According to Brewer, flowability can be measured using a cylinder of 75 mm and a diameter of 150 mm [20], as shown in Figure 2. It was calculated as an average of two diameters of flow for the mix after adding foam.

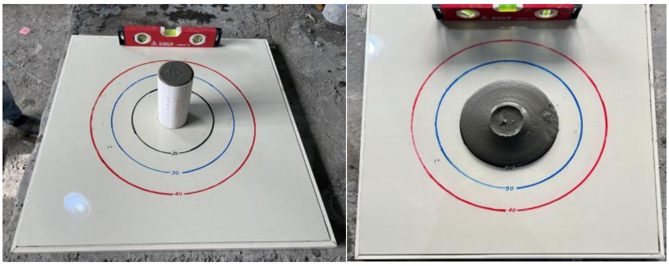

Figure 2: The flow ability test.

Compressive strength was measured by testing 100 mm concrete cubes based on EN 12390-3 [21] as shown in Figure 3. The tensile splitting test was made following the ASTM C496 standard [22] using cylinders with dimensions of 100mm diameter and 200 mm height and were tested at 7 and 28 days. An average strength of three cylinders for each mix was adopted. Three prisms of 100×100×400 mm sizes for the modulus of rupture test based on ASTM C78-15a [23].

Figure 3: Mechanical properties tests.

3. RESULTS AND DISCUSSION

3.1. Flowability

The flow diameter of both the unframed mix and foamed concrete was quantified, as shown in Figures 4 and 5. It was found that the spread diameter decreased when the foam was added to mixes. This finding was agreed with Nambiar and Ramamurthy [24]. The flow diameter for mixes with foam range between 20 to 17 cm is acceptable but low and can be proved by adding a superplasticizer without increasing the water/cement ratio [20]. With regard to sand grading, the spread diameter decreased when the grading of sand decreased. This result agreed with Siong et al. [25]. In terms of sand type, the spread diameter decreased when silica sand was used. This may be because of the surface texture, and It can be said that flowability depends on a filler type [26,27].

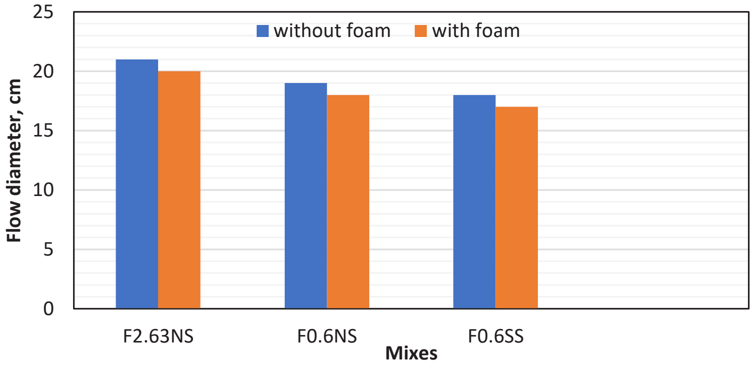

Figure 4: Flow diameter results for all mixes.

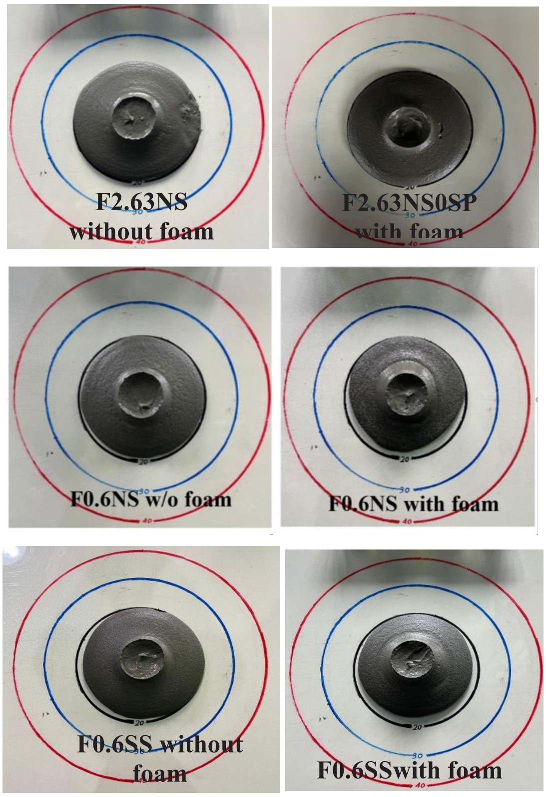

Figure 5: Flow diameter for all mixes with and without foam.

3.2 Mechanical Properties

To show the effect of sand size and type on the strength of foamed concrete, preliminary work was done on a 1700 kg/m ^{3} mix. Two types of sand were used: natural and silica sand. The natural sand was used with two gradings (less than 2.36 mm and less than 600 microns), while the silica sand size was less than 600 microns. Compressive strength at the age of 7 and 28 days is shown in Figure 6. The results of the compressive strength of foamed concrete mixes indicate that the compressive strength increased with age. At the same time, the compressive strength increased with a reduction in sand grading, and the best result was with silica sand.

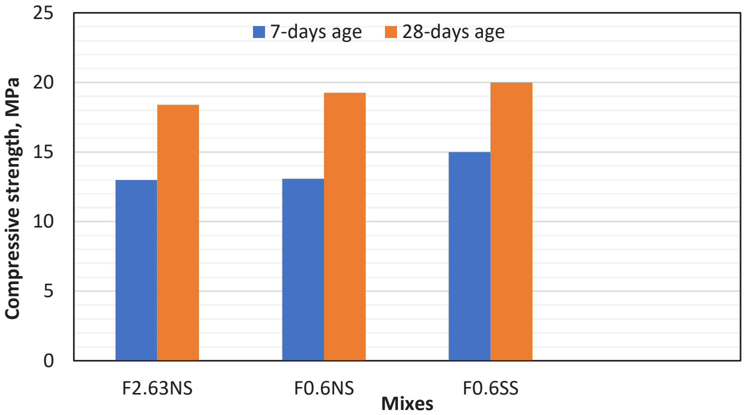

Figure 6: Compressive strength results for all mixes.

Figure 7 depicts the specimens' failure form when subjected to compression load. The samples generally failed without fracture, and it can be seen that, regardless of the size of the sand's particles, the cracks, including silica sand, are smaller than those containing conventional sand. Sand that was more finely ground has greater compressive strength. The compressive strength was enhanced by using finer filler material, which produced a more even and smaller air pore distribution [28].

Figure 7: Shape of failure under compression load.

Figures 8 and 9 demonstrate the foamed concrete mix's splitting tensile strength and rupture modulus findings at the ages of 7 and 28 days, respectively. In general, aging increases the splitting tensile strength. The silica sand can be shown to have increased tensile strength.

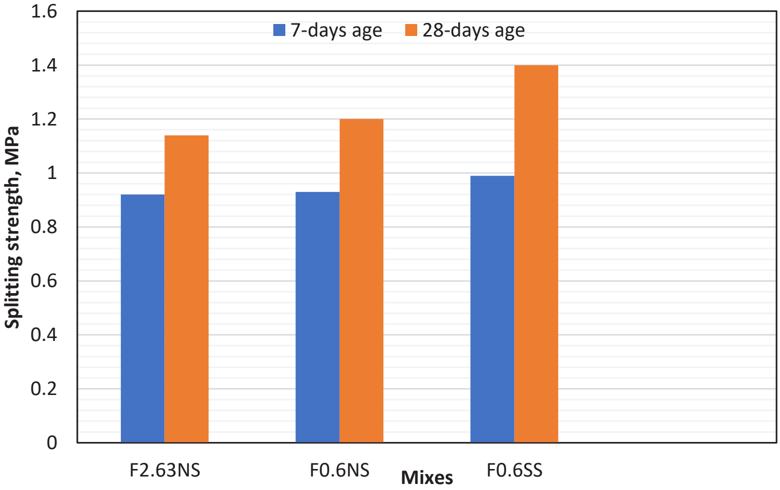

Figure 8: Splitting strength results for all mixes.

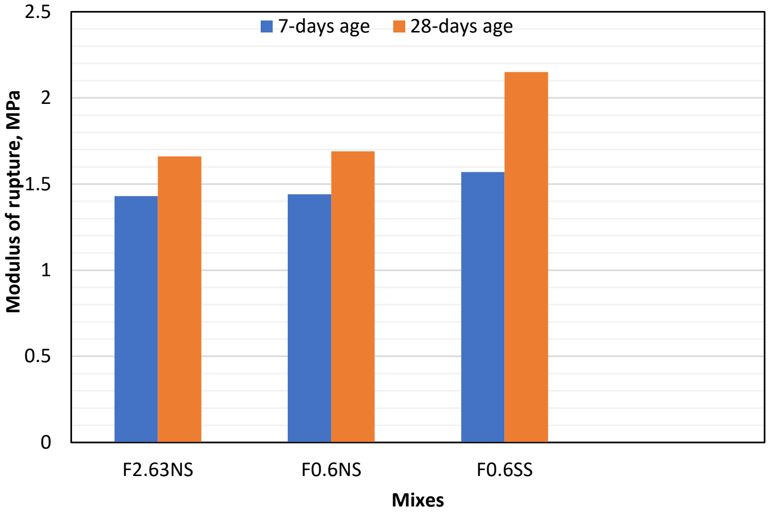

Figure 9: Modulus of rupture versus mixes.

As the sand fineness increased, the compressive strength also increased. The compressive strength was increased by constructing artificial air pores that were more evenly distributed and that were also smaller [28]. The tensile strength and compressive strength also increased due to the rise in compressive strength. Al-Ani et al. [12] agreed that adding silica sand in the foam mixture increased compressive strength. This is because the internal microstructure of foamed concrete has improved due to enhanced silica sand fineness [29]. Figure 10 illustrates how silica sand-containing foam concrete has a more regular and thick structure than foam concrete made with conventional sand. It is possible to obtain an equal distribution of air pores when the filler is finer, most likely by coating the bubbles with a uniform layer of paste, which prevents them from merging and overlapping. Additionally, finer sand reduces the volume of capillary pores [30].

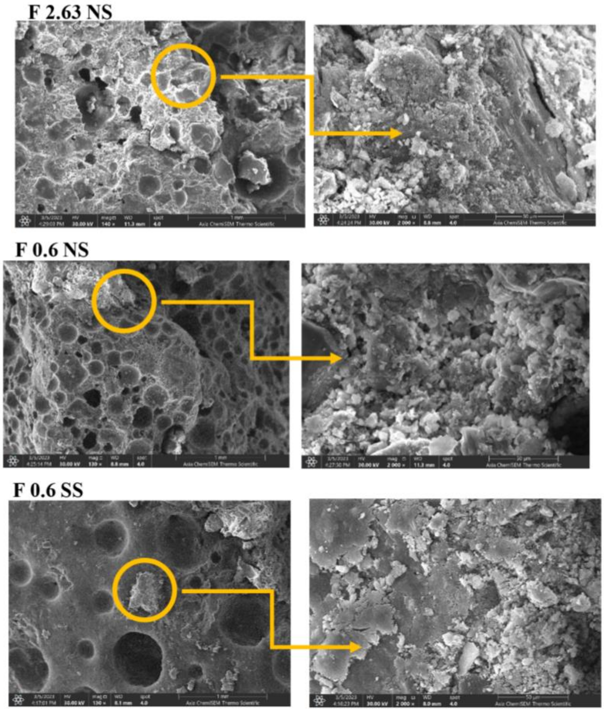

Figure 10: SEM test results for all mixes.

4. CONCLUSIONS

- The diameter of flow for concrete mix decreases when the foam is added to mixes, and it decreases with increasing the finesse of sand.
- The sand fineness was correlated with an increase in compressive strength.
- The tensile strength grew together with the increase in compressive strength, which is how the increase in compressive strength is reflected in it. Finer filler material helped in producing more uniform and narrower artificial air pores distribution, thus increasing the compressive strength.
- Because silica sand has a more uniform and dense structure than conventional sand, the qualities of hardened foam concrete, such as compressive strength and indirect tensile strength (splitting and bending), are increased.

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