International Journal of Thin Films Science and Technology

http://dx.doi.org/10.18576/ijtfst/120201

Heavy Mineral Sand as a Partial Replacement of Natural Sand in Ordinary and Standard Concretes

*Wael Zaghloul El-Sayad**

College of Engineering at Al-Qunfudha, Umm Al-Qura University, Makkah, Saudi Arabia

Received: 1 Nov. 2022, Revised: 22 Jan. 2023, Accepted: 22 Feb. 2023
Published online: 1 May 2023

Abstract: This study was conducted to investigate the effect of heavy mineral sand on the compressive strength and workability of ordinary and standard concretes. Concrete mixes were produced by adding heavy mineral sand to fine aggregate with 0%, 20%, 40%, 60%, 80% and 100% percent. Tests on specific gravity, workability and compressive strength were conducted on aggregate and concrete mixes. The results indicate that the compressive strength of concrete is not affected by the increase in the heavy mineral sand percentage. The concrete with heavy mineral sand as a fine aggregate was shown to have very-high workability owing to very fine metals and high surface area. The results denote that the heavy mineral sand improves the surface of concrete. The addition of heavy mineral sand enhances the concrete characteristics. The use of heavy mineral sand is an ingredient that can be used with concrete and leads to significant economic as well as functional benefits.

Keywords: ANOVA, Bauxite, Petroleum Waste Sludge, Mechanical, Density, Porosity, Shrinkage.

1 Introduction

Concrete is a homogeneous mass consisting of a binder (cement), coarse aggregate, fine aggregates (crushed stone, sand), water, and various additives that improve certain properties of concrete [1]. A very important factor to produce high-quality mix is the correct water-cement ratio. It is known that concrete has complex functions that require increased safety, several requirements is applied to its quality, including accurate calculation of proportions and compliance with the preparation technology that govern the technical conditions. Each component plays an important role. Fine aggregate is an integral part of the concrete mix, which fills the voids inside the concrete between the coarse aggregate, this is important because the porosity in concrete is the main source of its weakness. On the other hand, the shape and surface texture of the fine aggregate plays a key role, since the too many fines give a higher workability [2].

There is always a need to search for alternatives to the components of concrete, either for an economic or functional purpose. Research has increased in the last decade to find an alternative that achieves the same function as the component and achieves an economic benefit, or to examine whether this alternative is useful or not. Several studies were published in the recent years on the aggregate replacement. The works [3,4] were to reuse recycled concrete coarse aggregate as an alternative of aggregates, and they concluded that concrete was affected by a lower relative performance. The toughness and compressive strength of the concrete with recycled concrete coarse aggregate were lower than which of the natural aggregate [5]. With different percentages of Class F fly ash by weight fine aggregate was replaced, the result gave significant improvement in the strength properties of plain concrete [6]. After 28 days, the compressive strength with 20% waste glass substitute for fine aggregate was higher than of the reference concrete and the expansion of concrete was reduced by 66% [7]. Waste tire rubber was used instead of course and fine aggregate, which changed the failure from brittle to ductile, plastic one, but this was accompanied by a reduction in the compressive strength of the concrete [8]. In the research, the substitute for aggregates was industrially due to the need for that and the absence of a natural alternative. But having an inexpensive natural alternative would be a good thing if its natural uses were not more important than its use in concrete. So, we introduce the black sand as an alternative of fine aggregate.

Sand for concrete, which is used for the manufacture of concrete mortar, must meet the standards. The material is suitable if it contains less than ten percent of particles with a fraction up to 0.14 mm and no more than three percent of impurities represented by dust, silt, and clay. The presence of the impurities in the mixture can negatively affect the frost resistance and strength of the concrete, since it covers

*Corresponding author E-mail: wzsayad@uqu.edu.sa

the grains of sand, preventing them from properly connecting with the other components. Also, according to the standards, it is not allowed to contain large-sized particles of more than 10 mm, and the proportion of particles of 5-10 mm size must lie within five percent of the total mass of the bulk component. Organic inclusions in the material, represented by humus or plant elements, should be absent. Concrete production involves the use of coarse-grained sand with enough smaller grains, otherwise the concrete mixture will contain a lot of voids. The resulting voids will be filled with cement, which will increase the cost of the final product. It has been observed that the sand grains from the same fraction do not touch each other well, thus forming a larger free space. Therefore, a mixture of different particle sizes even if they are from residues gives higher density and compressive strength of concrete when compared to natural sand. [9].

Sands used in concrete mixes are classified by composition, origin, strength, color, and other physical characteristics.

Sand is the main component used in the manufacture of concrete mixes for the subsequent construction of buildings and structures. Based on the particle size, bulk materials are classified into two classes. The first class is characterized by the absence of microparticles less than 1.5 millimeters in diameter. This sand material is considered better, since the presence of a very fine aggregate negatively affects the density of settling of larger fractions. The second class, respectively, includes small components. That is why first-class bulk materials are used to prepare high-quality concrete.

In nature, there are so-called black sands found in various parts of the world such as Saudi Arabia as shown in Fig. 1. They consist of basalt, dark-colored heavy minerals and are formed because of leaching of lighter and lighter minerals. Basalt is a hard, black volcanic rock. Most often, their main minerals are hematite, ilmenite, and magnetite [10]. These Sands often form placer deposits. In 1981, 50 minerals out of 8 thousand known at that time were found in the black sands, as well as many rare earth elements.

a

b

Fig. 1: a) The location of black sand samples in Saudi Arabia; b) Photograph of Pure black sand sample and mixes with natural sand.

The main components of black sand are lava, which during an eruption falls into the water and there, after solidification, begins to break up into millions of small black grains. The tide carries the grains of sand to land, where they create an unusual sight for the human eye. In some coastal areas of the world, for example, on the beaches of India, Brazil, Ukraine, Egypt, and the kingdom of Saudi Arabia, black Sands are found. Their main mass is ilmenite (contains titanium). The black sands are often enriched with rare earth elements. Such sands are formed because of natural geological processes and immediately after their appearance have a black color and shine like metals. The main minerals are magnetite, ilmenite, and hematite. The elements C, O, Na, Mg, Al, Si, P, S, K, Ca, Ti, V, Cr, Mn, and Fe were found in the black sand in Saudi Arabia [11].

The type of black sand which we use occurs mostly in continental areas. It is heavy mineral sand. Heavy minerals are minerals which have a specific gravity above 2.9. There are almost all colors present among the heavy minerals, but they seem to be dark compared. Heavy mineral sands are usually composed of minerals that are relatively resistant to weathering. Heavy minerals are in most cases disseminated among the light-colored (and usually much larger) quartz grains but in certain conditions they tend to accumulate. This type of sand because of its minerals, it is a magnetizable material. Summing up the origin and application of heavy mineral sands in the modern world, it is necessary to note its advantages and widespread use in many areas of human life. To date, heavy mineral sands have not revealed their full potential and sometimes priority is not given to them because the largest quantities of it form parts of the coasts of the seas and oceans, that is, they contain salts. But after washing and cleaning them, it becomes of higher value than it is, since their origin is associated with lava emissions. Hence, we should not neglect that its origin is from lava, as it is a strong material that may give higher strength of the concrete.

The rest of the paper is organized as below: Section 2 illustrates experimental procedure, materials, and test specimens and test procedure. Results and discussion are presented in section 3. Section 4 provides the conclusion of the paper.

2 Experimental Procedures

2.1 Materials

The concrete mixtures were designed according to ACI for the ordinary concrete of grade M15 and for standard concrete of grade M25. The percentages 0%, 20%, 40%, 60%, 80%, and 100% of heavy mineral sands were used in mixtures. For each proportion, 8 cubes were prepared, and the workability was determined. The materials used were Portland cement, natural sand, heavy mineral sand, crushed local stone as coarse aggregate and distilled fresh water. The sand and coarse aggregates were washed well and then left to dry and then, the heavy mineral sand was mixed with the natural sand in the proportions mentioned previously.
Heavy Mineral Sands: were obtained at the estuaries of the valleys near the coast of Red Sea, in southern Saudi Arabia.
Natural Sands: They are the sands of valleys, which are the sands used in ready-mixed concrete mixers in the Kingdom.
The standard tests [12-15] were performed on the mentioned sand ratios and coarse aggregate to obtain the physical properties listed in table 1.

The above table showed that the specific gravity of samples contains heavy mineral sand is in the range from 3 to ≈5. The specific gravity is increasing with the increase of heavy mineral sand content. Concrete mixes were designed using ACI [16]. For M15 and M25, the proportions from mix design in kg/m^3 were calculated and given in table 2.

Table 1: The physical properties of fine and coarse aggregates.

Material	Specific gravity	Absorption (%)	Sieve analysis	Max. aggregate size
0% of heavy mineral sand	2.8	1.15	Zone III	-
20% of heavy mineral sand	3.05	0.8	Zone IV	-
40% of heavy mineral sand	3.33	0.8	Zone IV	-
60% of heavy mineral sand	3.85	0.6	Zone IV	-
80% of heavy mineral sand	4.13	0.1	Zone IV	-
100% of heavy mineral sand	4.8	0.1	Zone IV	-
Coarse aggregate	2.65	1.85	-	40

Table 2: Mix design proportions and slumps with the heavy mineral sand content in the fine aggregate.

Grade	heavy mineral sand (%)	Water (kg)	Cement (kg)	Fine agg. (kg)	Coarse agg. (kg)	Slump (mm)
M15	0	197	289.5	632.3	1332	62.5 - 73
	20	195.3	289.5	666.6	1351.4	92.5 - 93
	40	196.1	289.5	679.3	1390	92.5 - 94
	60	195.4	289.5	663	1428.6	96 - 140
	80	192.2	289.5	781.3	1428.6	160 - 172
M25	0	195.5	383.7	605	1275	49.5 - 55
	40	194	383.7	637.8	1293	60.0 - 65
	60	194.8	383.7	650	1330	55.6 - 57
	80	206	383.7	697.1	1367	58.0 - 60

2.2 Test Specimens and Test Procedure

The components were placed in a concrete mixer and were mixed until the specified time for the mixing process according to the standard specifications [17]. The slump test of concrete was performed on all mixtures as indicated by the ASTM [18]. The readings of average slumps are given in table 2 and plotted with heavy mineral sand percentages with Figs. 2 and 3. Then the mixes were placed in clean metal cubes and compacted by hand.

The 150 mm size concrete cubes were used as test specimens to determine the compressive strength and the workability of fresh concrete was measured in terms of slump values. The concrete was treated by the conventional method with fresh water at temperatures between 28 and 32° C.

The cubes were tested for compressive strength after 7 days and 28 days. The samples were weighed, then exposed to the crushing machine and the readings were recorded as shown in tables 3 and 4 and plotted in Figs. 4 and 5.

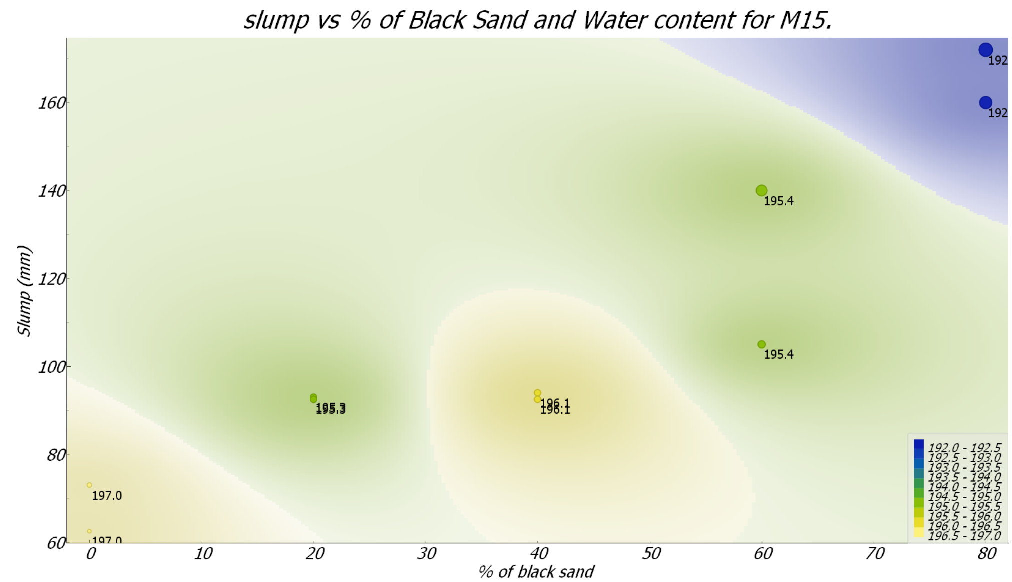


Fig. 2: Average slumps in (mm) according to the concrete grades M15 versus the heavy mineral sand percentages in the concrete.

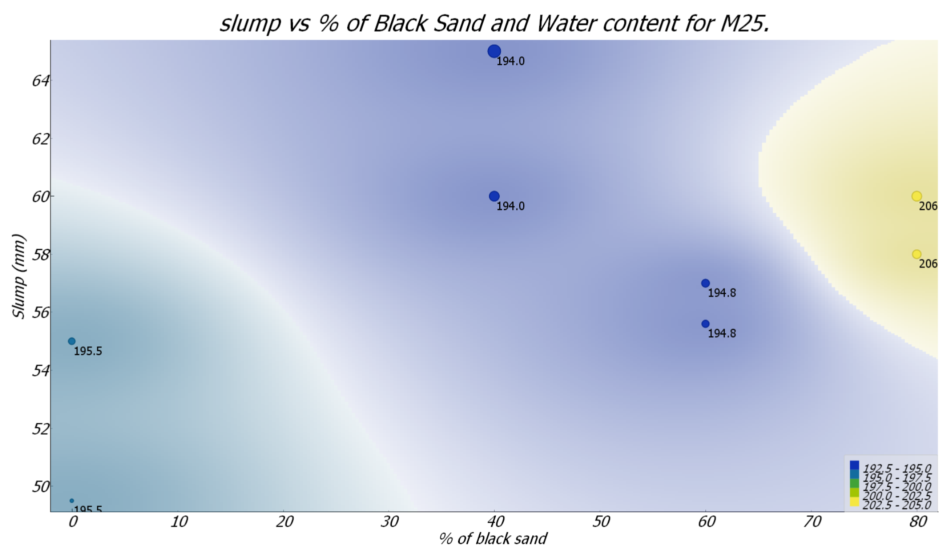


Fig. 3: Average Slumps in (mm) according to the concrete grades M25 versus the heavy mineral sand percentages in the concrete.

Table 3: Average compressive strength with heavy mineral sand after 7 days and 28 days for M25.

Heavy mineral sand (%)	Average compressive strength (Mpa)	
	(After 7 days)	(After 28 days)
0	21.5	49.2
20	22.9	45.9
40	23.55	43
60	24.6	43.9
80	29.9	45
100	30.1	47

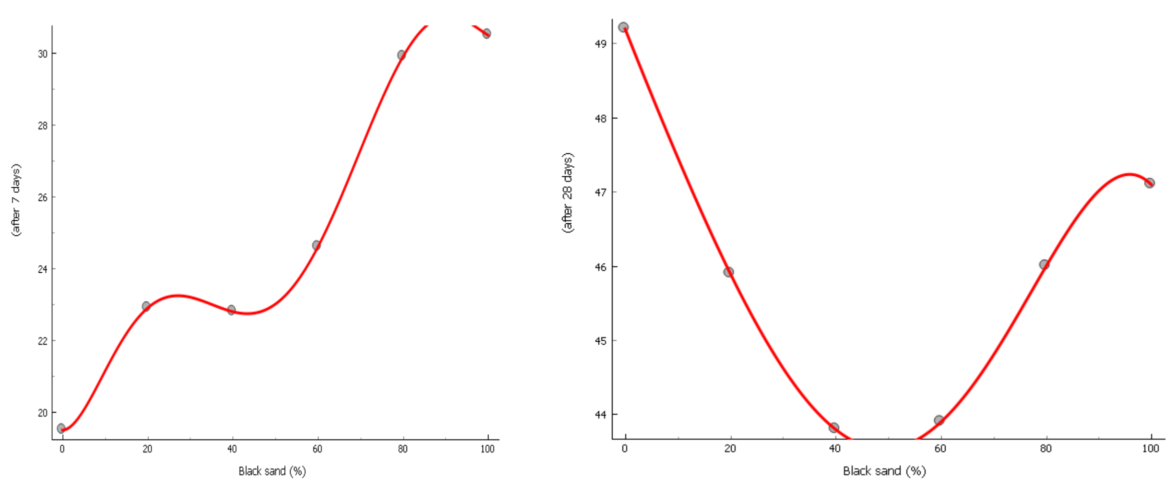
Table 4: Average compressive strength with heavy mineral sand after 7 days and 28 days for M15.

Heavy mineral sand (%)	Average compressive strength (Mpa)	
	(After 7 days)	(After 28 days)
0	19.5	49.2
20	22.9	45.9
40	22.8	43.8
60	24.6	43.9
80	29.9	46
100	30.5	47.1

3 Results and Discussion

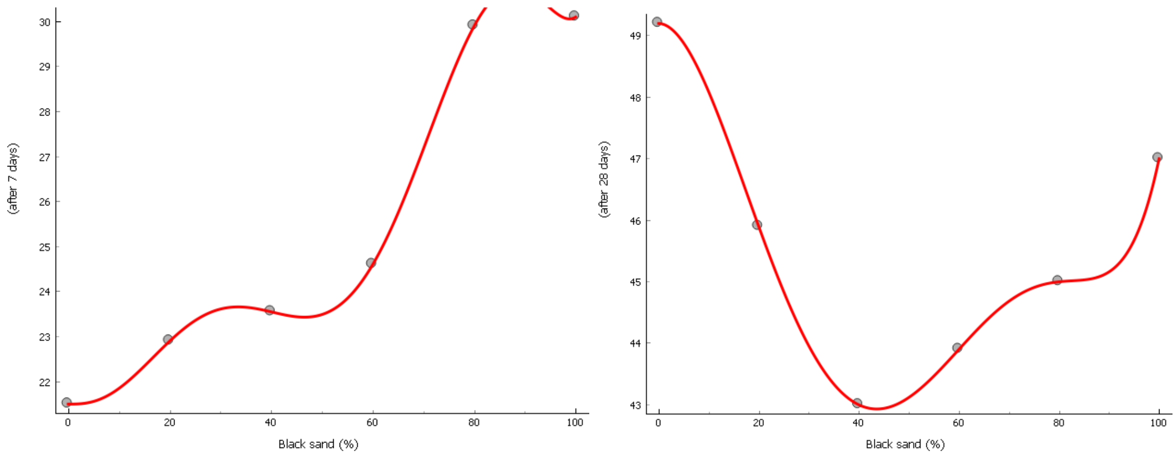
Due to the nature of the heavy mineral sand, rich in silica and minerals, and amorphous, it is vulnerable to chemical attack at heigh the alkaline conditions provided by the water-cement phase in concrete. The nature of the heavy mineral sand reactivity has important implications in its utilization in concrete. This chemical attack clearly affects the properties of concrete, especially on the workability, in the initial stages of casting. The results of the slump tests are presented in table 2 and Figs. 2 and 3, showing an increasing slump with increasing heavy mineral sands percentages in the concrete mixes of M15 grade. The $\frac{w}{c}$ ratio of the mix was 0.57. The results indicated that the amount of slump increases in approximately the same percentage at the rates of heavy mineral sand 20% and 40% and reaches 125% of its reference value. But at 60% the increase is much greater and reaches approximately 200%, and at 80% of the heavy mineral sand the increase in slump is approximately 225%, this is because the ability of heavy mineral sand to absorb water is less than the ability of natural sand to do so, and also as a result of the presence of various materials, especially minerals within the heavy mineral sand, which interacted with the rest of the mixture and produced more liquid concrete. For M25 concrete there was an increase in slump, but it was much less than that on M15. Since the w / c ratio in the mix was 0.43, it is smaller than that of the M15, so ingredients tend to set faster and have less fluidity. It can be concluded that all proportions of heavy mineral sand with ordinary concrete give high fluidity. As for standard concrete, ratios smaller than 50% help to make a difference in liquidity. We need a method to examine the relationship between the components with chemically heavy mineral sand.

From tables 3 and 4 and Figs. 4 and 5, despite the high fluidity of M15 concrete, the compressive strength of the concrete increased by increasing the proportion of heavy mineral sand after 7 days, and this increase reached rates greater than 30% with the proportion of heavy mineral sand greater than 50%. As for the grade M25, the compressive strength for it with percentages of less than 60% of the heavy mineral sand increased by less than that with the degree M15, but at 80% it achieved the same rate of increase with respect to M15 and it was 30%. For the two grades and after 28 days, the compressive strength appears almost unchanged, it just decreases by a small percentage that does not exceed 6%. We can say that compressive strength of concrete at later age is virtually unaffected by the percentage of heavy mineral sand.



(a) (b)

Fig. 4: Compressive strength (in MPa) with heavy mineral sand for M15; a) after 7 days and b) after 28 days.



(a) (b)

Fig. 5: Compressive strength (in MPa) with heavy mineral sand for M25; a) after 7 days and b) after 28 days.

4 Conclusions

Based on the results of above-mentioned experiments, it can be concluded from this research the following:

1. The data presented in this paper show that there is great benefit in using heavy mineral sand in concrete as it can be used as an excellent alternative to natural sand, and it plays the role of some costly chemical admixtures.
2. The tests showed an improvement in the specific gravity, workability, and compressive strength of the concrete.
3. It has been concluded that heavy mineral sand up to 80% can be incorporated into ordinary concrete and above 50% with standard concrete as an alternative to fine aggregate without any harmful effects.
4. Improving the shape and texture of the concrete using the heavy mineral sand.

References

[1] H. K. Steven, Beatrix.K, and C. P. William, Design and control of concrete mixtures, Skokie, IL: *Portland Cement Association.*, **5420** , 60077-1083(2002).

[2] A. M. Neville, *Concrete technology*, England: Longman Scientific & Technical., **438** (1987).

[3] M. Safiuddin, J. Alengaram, M. Rahman, A. Salam, and M. Zamin Jumaat, Use of recycled concrete aggregate in concrete: a review, *Journal of Civil Engineering and Management.*, **19 (6)** 796-810(2013).

[4] A. M. Wagih, H. Z. El-Karmoty, M. Ebid, and S. H. Okba, Recycled construction and demolition concrete waste as aggregate for structural concrete, *HBRC Journal.,* **9(3)**, 193-200(2013).

[5] S. W. Tabsh and A. S. Abdelfatah, Influence of recycled concrete aggregates on strength properties of concrete, *Construction and building materials.*, **23(2),**1163-1167(2009).

[6] R. Siddique, Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete, *Cement and Concrete research.*, **33**(4) 539-547(2003).

[7] Z. Z. Ismail and E. A. AL-Hashmi, Recycling of waste glass as a partial replacement for fine aggregate in concrete, *Waste management.*, **29 (2)**, 655-659(2009).

[8] "*Sabinet Compressive strength of concrete utilizing waste tire rubber.*" https://journals.co.za/content/sl_jeteas/1/1/EJC156734 (accessed Jan. 1, 2023).

[9] A. De Rossi, M. J. Ribeiro, J. A. Labrincha, R. M. Novais, D. Hotza, and R. F. P. M. Moreira, Effect of the particle size range of construction and demolition waste on the fresh and hardened-state properties of fly ash-based geopolymer mortars with total replacement of sand, *Process Safety and Environmental Protection.*, **129** 130-137(2019).

[10] G. W. Thorsen, *Mineralogy of black sands at Grays harbor,* Washington: Washington Division of Mines and Geology Report of Investigations., **23,** 29(1964).

[11] H. Khwaja et al., Study of Black Sand Particles from Sand Dunes in Badr, Saudi Arabia Using Electron Microscopy, *Atmosphere.,* **6(8),** 1175-1194 (2015).

[12] "ASTM C70 - *20 Standard Test Method for Surface Moisture in Fine Aggregate.*" https://www.astm.org/Standards/C70.htm (accessed Jan. 1, 2023).

[13] "ASTM C127 - *15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate.*" https://www.astm.org/Standards/C127.htm (accessed Jan. 1, 2023).

[14] "ASTM C128 - *15 Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate.*" https://www.astm.org/Standards/C128.htm (accessed Jan. 1, 2023).

[15] "ASTM C136 / C136M - *19 Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.*" https://www.astm.org/Standards/C136.htm (accessed Jan. 1, 2023).

[16] "ASTM C31 / C31M - *19a Standard Practice for Making and Curing Concrete Test Specimens in the Field*," ASTM International, West Conshohocken, PA, 2019.
[17] "ASTM C143 / C143M - *20 Standard Test Method for Slump of Hydraulic-Cement Concrete*." https://www.astm.org/Standards/C143 (accessed Jan. 1, 2023).
[18] "ASTM C172 / C172M - *17 Standard Practice for Sampling Freshly Mixed Concrete*." https://www.astm.org/Standards/C172.htm (accessed Jan. 1, 2023).