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Experimental Investigation of Strength and Water Absorption of Concrete Containing Desert Sand

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ABSTRACT

The purpose of this study is to investigate the effect of desert sand as a replacement on the tensile and compressive strength of concrete. To this end, a total of 180 cubic specimens (15×15×15 cm) and 90cylindricalspecimens (15×30 cm) were made with three concrete classes of C20, C25, and C30. Control samples (samples without desert sand) and samples containing 5%, 10%, 15%, and 25% sand were also produced. They were processed in mineral-free water at 7, 14, 21, and 28 days. They were then subjected to pressure and tension tests by a 200-ton digital concrete breaker jack. For the water absorption test, 15 cylindrical samples (7.5×15 cm) were made for C25 and 0%, 5%, 10%, 15%, and 20% desert sand. They were then tested after 28 days. The results showed that the compressive strength at the age of 28 days gradually increased by adding the sand. It reached the highest for C20 containing 10% sand. However, it reached the highest foe C25 and C30 containing 5% sand. Adding sand over 20% leads to decreasing compressive strength. The tensile strength of C25 and C30 concrete containing 5% sand and C20 concrete containing 10% sand was the highest compared to the control sample. Adding sand up to 10% leads to decreased water absorption, and then it increases after adding sand.

1. Introduction

Today, owing to the expanded construction industry in Iran and especially the tendency of engineers to the construction of large and high-rise structures, increasing safety in the production and execution of structures seems necessary. Among the appropriate solutions for the implementation of complex projects, especially structures located in earthquake-prone areas, the acquisition of new products from building materials is essential to increase the reliability and safety of construction and reduce costs. Concrete is known as one of the most widely used building materials in the world. The study of certain properties, such as reliability, quality and density of concrete is of particular importance. In recent years, access to good quality natural sand has decreased, and this seems to be a global trend. Environmental issues arise regarding the unauthorized removal of natural sand from the concrete mixing scheme. These arguments are mostly related to the protection of rivers against erosion and the importance of natural sand as a filter for the underground water (Bahoria et al., 2013). Extraction and removal of sand and soil particles by wind from desert surfaces causes the depletion and destruction of some of the most important soil components. In addition, the structure of the earth in desert surfaces is such that it is not quickly renewed and this will cause the infrastructure destruction (Goudie, 2014). Storms send hundreds of tons

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of sand to people every year, and the constant flow of dust storms continues due to the location of these areas in the heart of the desert. Deserts have always been one of the centers of flowing sands, and this has caused these areas to witness dozens of high-intensity sandstorms and strong winds with dust and strong winds every year (Broomandi et al., 2017). In an experimental study, Noufal and Manju (2016) investigated the effect of using river sand in concrete construction. The results showed that this sand can be an appropriate alternative in concrete. Cakir and Sofyanli (2015) studied the effect of microsilica on the physical and mechanical properties of concrete made with recovered aggregate. The results showed a continuous and significant improvement in the tensile strength of concrete containing recycled aggregates combined with microsilica. Che et al. (2019) studied the strength and behavior of concrete made with desert sand. The main purpose of this paper is to prepare high-strength fiberglass concrete using a large volume of ash and to replace fine river sand with sand taken from the desert. The results showed that the use of 0.36 ratio of desert sand to adhesive paste increases the compressive strength and tensile strength and can significantly reduce the final cost of concrete production. Considering the adaptation of desert sand in concrete construction and the challenges of construction sand shortage in the construction industry, Neumann and Curbach (2018) studied the thermal behavior of desert sand for the production of construction materials. The results showed that the pH of the sifted, cleaned and dried samples changed from acidic to neutral or even alkaline. In general, desert sand can be used as a substitute for fine aggregates. Zahrai et al. (2016) concluded in their study that the consumption of microsilica gel or concrete additive will create unique properties including reducing the cement grade by 5 to 10%, reducing detached aggregates and water logging and increasing the mechanical strength of concrete. Benchaa (2018) studied the effect of using crushed sand, river sand and desert sand (Algerian desert) and the combination of two or three of these sands on the properties and strength of fresh, self-compacting concrete. The experimental results showed that the combination of crushed and river sands is effective in improving the strength of self-compacting fresh concrete. However, crushed and desert sand compositions as well as river and desert sand, especially in compositions where the amount of desert sand is higher than 50%, a decrease in efficiency and strength was observed. Tebbal and Rahmouni (2016) studied the effect of broken sand composition in concrete as well as gradual replacement of aerated sand on the stability of high performance concrete in aggressive environments. This study showed that when broken and Aeolian sand is mixed with concrete with the ratio of 2/3 and 1/3, respectively, the performance parameters of high-performance concrete improved, and the mechanical properties experienced improvement in non-sulfated medium. If more than 1⁄3 of Aeolian sand is used, in addition to the amount of additional water needed to provide the properties of concrete, it will also reduce its strength. In general, adding Aeolian sand to broken sand reduces the mechanical properties of concrete in a sulfated environment, and the water absorption coefficient increases after adding Aeolian sand to broken sand.

Zhang et al. (2020) investigated the effect of desert sand and cooling regime on the compressive strength of high strength concrete after high temperature. In this study, desert sand with different percentages (0%, 20%, 40%, 60%, 80% and 100%) was used instead of ordinary sand in concrete mix. High-strength desert sand-based concrete is subjected to two cooling regimes (air cooling and water cooling) and different temperatures (20°C, 400°C, 500°C, 600°C, 700°C and 850°C). The results showed that the compressive strength is higher with air cooling than with water cooling. In addition, the highest compressive strength appears in 20% ratio. The compressive strength gradually decreases with ratios more than 20%. In one study, desert sand as a substitute for local sand in concrete production was used to investigate the mechanical behaviors after different temperatures. Desert sand replaces local sand in ratios (0-100). The experimental results showed that increasing the desert sand ratio improves compaction. With an optimal ratio of 40% desert sand, the compressive strength (at room temperature) and flexural strength (after increasing the temperature) increased. However, an increase in the desert sand ratio of more than 40% decreased the resistance (Zhang et al., 2019). In another study, the effect of chemical and physical properties of Kenya and Chad desert sand was investigated on the compressive strength. After evaluating the chemical and physical properties of the collected samples, they were used as a complete replacement for ordinary fine materials in concrete. The compressive strength of concrete on cubic samples was measured after 7, 14 and 28 days. By increasing processing days, the compressive strength of all concrete samples increased, but in general, the compressive strength of ordinary concrete was higher than concrete made of desert sand (Danembaye et al., 2017). Therefore, the criterion for accepting a type of stone material as an ideal material is a function of various parameters, which makes it necessary to study the effect of each of these parameters on the physical and mechanical parameters of concrete. Since the elements of reinforced concrete structures can be woven together into a continuous and integrated network, using reinforced concrete in the design of the structure gives it unparalleled flexibility (Barati et al., 2016).

2. Importance of the Study

Flowing sand with a relatively low modulus of softness is among the materials abundantly found in deserted areas. Despite these substances, people in these areas face problems with sandstorms, which lead to an increase in lung and respiratory diseases. It is hoped that by reducing this waste from desert areas, we can help improve these areas and increase the quality of life. On the other hand, the phenomenon of flowing sand in deserted areas has always caused a lot of damage to the transport sector and causes many problems for roads and railways. This has led researchers to stabilize flowing sands or help reduce the damage caused by the presence of this waste in nature by reducing its volume. Therefore, by removing this substance from the nature, it is possible, to some extent, to increase the safety of public transportation systems. Since flowing sand moves under the influence of winds and storms in the region, and in any case, these particles sit on the sand mines, washed sands and crusher depots of those areas and combine with the construction materials. Therefore, by estimating the appropriate percentage of desert flowing sand and using it in the concrete mixing plan, it is possible to help significantly eliminate this pollutant in the environment by reducing the percentage. Therefore, the purpose of this study is to obtain concrete with suitable mechanical properties. This experimental study investigates the effect of combining desert and ordinary sand on the concrete properties. Compressive strength, tensile strength and water absorption of concrete at different ages are examined. It is hoped that this will be a step towards expanding the information and increasing the general knowledge of engineers and construction workers with the characteristics of this material in the concrete industry.

3. Material and Methods

In order to improve the knowledge of constriction materials, different tests were conducted including granulation test, aggregate resistance to impact, aggregate resistance to pressure, determination of breakage percentage of coarse aggregates, determination of abrasion percentage, sand value, density and water absorption of aggregates. After recognizing the selected materials, 15 mixing schemes were selected using conventional materials and desert sand through the existing mixing scheme theories. Without changing the total weight of the sand, desert flowing sand was replaced the sand as a weight percentage in concrete, which are 5, 10, 15 and 20. The softness modulus of each stage is obtained by observing the mixing scheme. The ratio of water to cement is similar in all stages. The specimens were then subjected to destructive compressive strength tests at ages 7, 14, 21 and 28 and destructive tensile strength tests at ages 7 and 28. Test conditions for fabrication and processing of all concrete samples were in accordance with ASTM C192. After performing the compressive and tensile strength tests, comparing the results with the control sample and the available laboratory research, the optimal mixing scheme was introduced in order to improve the efficiency of native materials.

3.1. Aggregates Specifications

The properties of fine and coarse aggregates are determined according to the standards as following: sand value (AASHTO T176), percentage of relative humidity (ASTM C566), abrasion percentage (ASTM C131), percentage of breakage (ASTM D5821), coarse aggregate water absorption (ASTM C127), fine aggregate water absorption (ASTM C128), and fine aggregate water absorption (ASTM C136). The maximum diameter of aggregates is 19 mm. Therefore, the physical and mechanical properties of aggregates for the control sample (0% of desert runoff sand) are shown in Table 1.

3.2. Mixture Scheme

To determine the appropriate mixture scheme, 15 schemes were determined for C20, C25, and C30 concrete using strength capacity. For each scheme, three cubic specimens (15×15×15) underwent compressive strength test at ages of 7, 14, 21, and 28 days. Three cylindrical specimens (15×30 cm) underwent destructive tensile strength at ages of 7 and 28 days using a 200 ton jack. Table 2 shows the mixing ratio in this study.

3.3. Constructing, molding and processing

A total of 285 specimens were made. All underwent compressive strength, tensile, water absorption tests in the laboratory after processing following the standards listed in Table 3.

3.4. Compressive Strength Test

The compressive strength test was conducted according to British standard (BS EN12390-3) on 180 specimens (15×15×15) for the concrete classes (C20, C25, and C30) for the control specimen and those containing 5%, 10%, 15%, and 20% sand in mineral-free water at ages of 7, 14, 21, and 28 days. The concrete specimens were subjected to a pressure test by applying a compressive axial force with a 200 ton digital concrete breaker jack to the point where they could no longer withstand more force. Fig. 1 shows the compressive strength test of the specimens.

3.5. Tensile Strength Test

The tensile strength test was conducted according to ASTM C496 [23] on 90 cylindrical specimens (30*15) for three concrete classes (C20, C25, and C30) for the control specimen and those containing 5%, 10%, 15%, and 20% sand in mineral-free water at ages of 7and 28 days.The concrete specimens were subjected to a pressure test by applying a compressive axial force with a 200-ton digital concrete breaker jack to the point where they could no longer withstand more force. Figure 2 shows the tensile strength test of the specimens.

Table 1. Physical and mechanical properties of fine/coarse aggregates for samples' control

Properties	Aggregate	Fine	Coarse
Physical	Relative Humidity (%)	1	2
	Saturated specific weight with dry surface (g/cm^3)	2.67	2.48
	Water Absorption (%)	1.5	3.9
Mechanical	Sand Value (%)	-	82
	Breakage (%)	35	-
	Abrasion (%)	27.1	-
	Softness Module	-	3.04

Figure 1. A view of used compressive strength test (UCS)

Table 2. Mixture Ratio during the tests

Scheme No.	Concrete Class	Desert Sand Percentage	Water/Cement Ratio	Weight of Constructional Materials in one cubic meter of concrete (kg)				
				Cement	Water	Coarse Sand	Fine Sand	Desert Sand
1	C20	0	0.55	322	198	935	857.0	00.0
2	C25	0	0.50	356	198	920	843.0	00.0
3	C30	0	0.49	369	200	912	836.0	00.0
4	C20	5	0.55	322	198	935	814.1	42.8
5	C25	5	0.50	356	198	920	800.8	42.1
6	C30	5	0.49	369	200	912	794.2	41.8
7	C20	10	0.55	322	198	935	771.3	85.1
8	C25	10	0.50	356	198	920	758.7	84.3
9	C30	10	0.49	369	200	912	752.4	83.6
10	C20	15	0.55	322	198	935	728.4	128.5
11	C25	15	0.50	356	198	920	716.5	126.4
12	C30	15	0.49	369	200	912	710.6	125.4
13	C20	20	0.55	322	198	935	685.6	137.1
14	C25	20	0.50	356	198	920	674.4	134.8
15	C30	20	0.49	369	200	912	668.8	133.7

Table 3. Specimens Properties related to used materials

Test	Standard	Shape	Dimension (cm)	Quantity
Compressive Strength	BS EN12390-3	Cubic	15×15×15	180
Tensile Strength	ASTM C496	Cylindrical	30×15	90
Water Absorption	BS 1881-122	Cylindrical	7.5×15	15

Figure 2. Utilized tensile strength test

Figure 3. Breakage condition of compressed specimens

3.6. Water Absorption of Concrete

The water absorption test was conducted according to British standard (BS 1881-122). To this end, 15 cylindrical specimens (7.5×15 cm) were constructed and processed in the water for 28 days. Then the dry weight of specimens were measured and then soaked in the water for half an hour so that the specimen surface was 5 cm below the water surface. Then the samples were taken out of water and their surface was dried with a cloth. Then the samples were weighed and recorded as wet weight and water absorption percentage of 30 minutes was measured.

4. Results and Discussions

The present study is a laboratory and applied research. In this study, a combination of desert and ordinary sand was used, and the behavior of the specimens under pressure, tension and water absorption was investigated. For this purpose, a compressive and tensile strength device was used. To investigate the water absorption of concrete samples, the percentage of water absorption was obtained by soaking the specimens in water and by weighing the samples. Finally, the results are plotted on graphs and compared with the control sample. The results showed that the use of desert sand can affect the strength of concrete.

4.1. Compressive Strength

Figure 3 shows the compressive strength of specimens. How the specimens break under the compressive strength test shows that the concrete is homogeneous, and the compressive force is properly applied. The following are the results of compressive strength of concrete of different classes.

C20 Concrete: A total of three specimens were constructed for each mixture scheme according to different ages for various percentages so that 15 specimens (total of 60) were subjected to the compressive strength. The mean compressive strength was calculated. Fig. 4 shows the compressive strength of C20 concrete specimens at 7, 14, 21 and 28 days of age. By adding 10% Desert sand, the compressive strength equals 34.48 MPa and 30.5 MPa for the control for 28-day concrete. Here, the maximum compressive strength is higher by 13% compared to the control. The compressive strength increased when desert sad was added for all percentages even at 20% scheme, showing the fact that using desert sand can improve the concrete performance (compressive strength, UCS).

C25 Concrete: A total of three specimens were constructed for each mixture scheme according to different ages for various percentages so that 15 specimens (total of 60) were subjected to the compressive strength. The mean compressive strength was calculated. According to Fig. 5, the maximum compressive strength of C25 is 37.66 MPa. Using desert sand changed the compressive strength. By adding 10% Desert sand, the compressive strength equals 35.09 MPa for the 28-day concrete. The compressive strength increased when desert sad was added for all percentages even at 15% scheme.

C30 Concrete: A total of three specimens were constructed for each mixture scheme according to different ages for various percentages so that 15 specimens (total of 60) were subjected to the compressive strength. The mean compressive strength was calculated. According to Fig. 6, the compressive strength is higher for different percentages compared to the control so that adding 5% sand in the 28-day specimen showed the highest compressive strength (39.8 MPa). Adding 10% sand led to decreased compressive strength in comparison with the highest value.

4.2. Tensile Strength

A total of three specimens were constructed for each mixture scheme according to different ages for various percentages so that 15 specimens for each age (total of 90) were subjected to the tensile strength. The mean tensile strength was calculated. In the following, tensile strength diagrams are seen for different concrete classes.

C20 Concrete: Fig. 7 shows the tensile strength of C20 at 7 and 28 days of age. As it can be seen, adding 10% sand led to 3.084 MPa for tensile strength. The tensile strength of the control was 2.73 MPa. Similar to the compressive strength, the tensile strength is the highest for 10% sand.

C25 Concrete: As seen in Fig. 8, adding 5% sand led to the tensile strength of 3.486 MPa. It was 2.947 for the control. The maximum tensile strength was 18% higher than that of the control. Adding sand at different percentages except for the 20% has led to increased tensile strength. Adding 20% sand led to the tensile strength, which is almost equal to that of control, showing the fact that using sand improves the tensile strength of concrete.

C30 Concrete: As seen in Fig. 9, adding 5% sand led to the tensile strength of 3.57MPa. It was 3.23 for the control. The maximum tensile strength was 10% higher than that of the control. Adding sand at different percentages except for the 20% has led to increased tensile strength. Adding 20% sand led to the tensile strength, which is almost equal to that of control, showing the fact that using sand improves the tensile strength of concrete.

4.3. Water Absorption

Fig. 10 shows the water absorption trend of C25 specimens at the age of 28 days. As seen, water absorption percentage is 1.27% for the control. Adding sand led to reduced water absorption so that adding 10% sand led to the least water absorption (1.18%). After that, adding more sand caused higher water absorption so that 20% sand caused 1.26% water absorption, which is lower than the control.

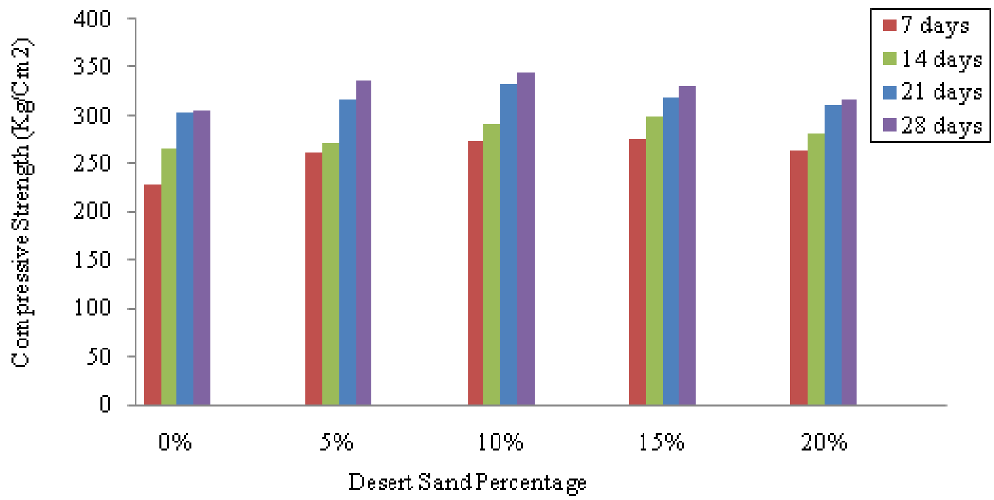

Figure 4. Compressive Strength of C20 Concrete

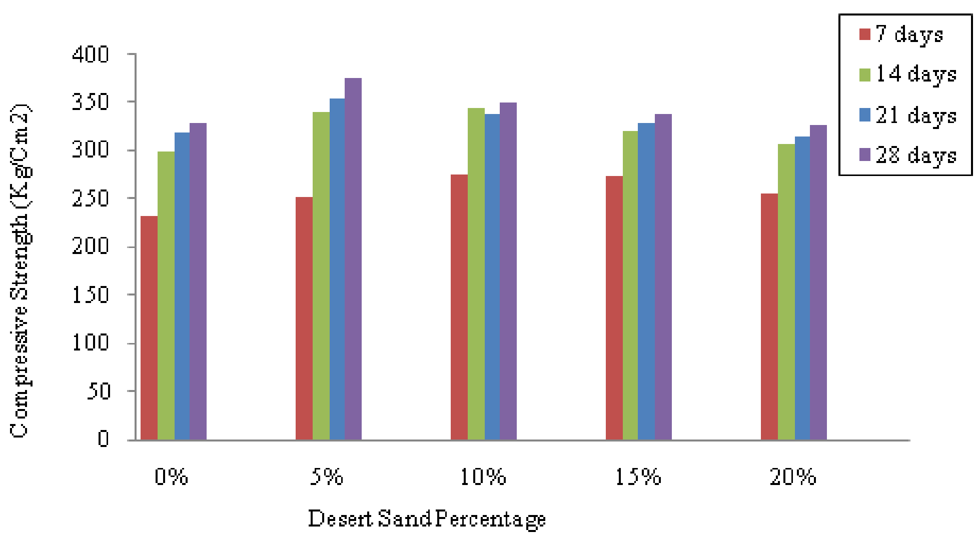

Figure 5. Compressive Strength of C25 Concrete

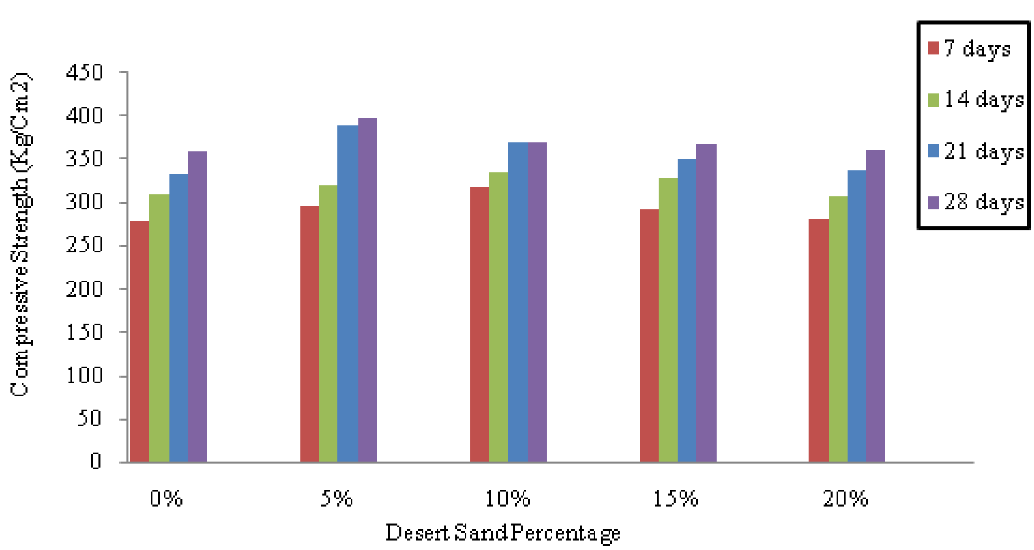

Figure 6. Compressive Strength of C30 Concrete

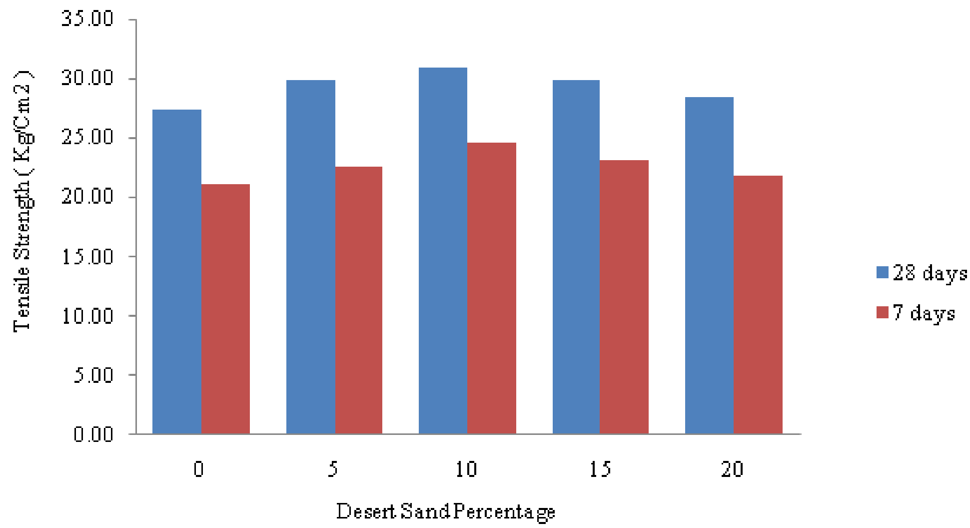

Figure 7. Tensile Strength for C20

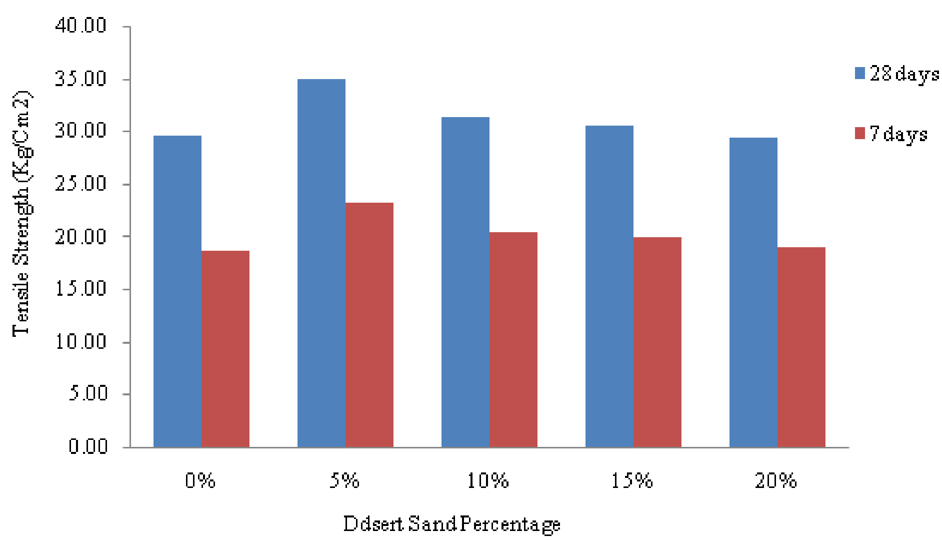

Figure 8. Tensile Strength for C25

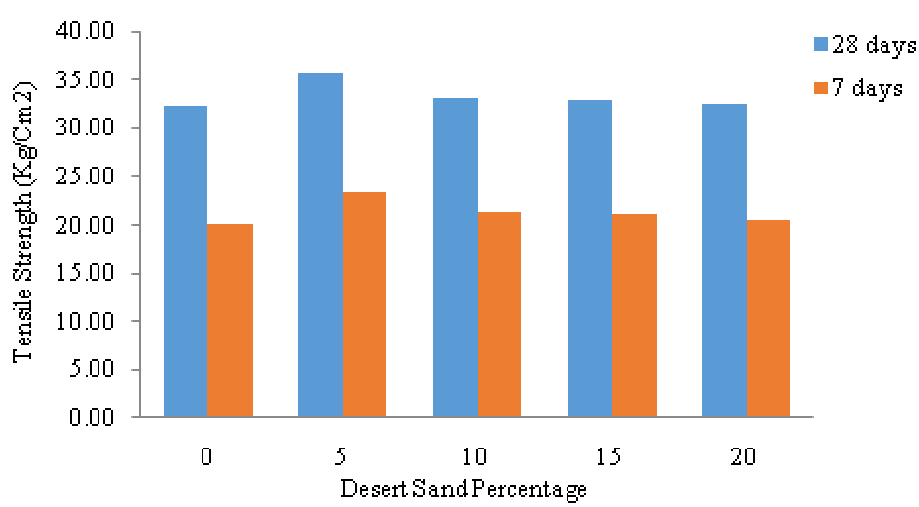

Figure 9. Tensile Strength for C30

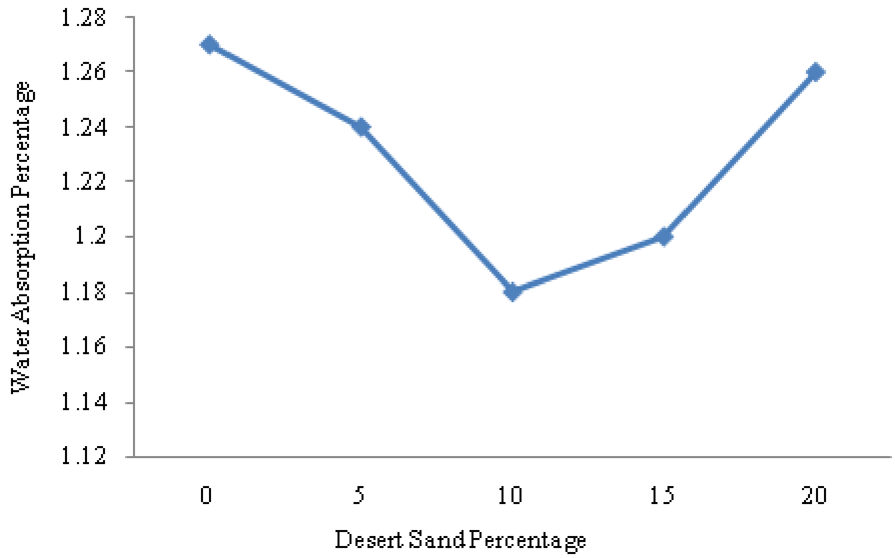

Figure 10. Water Absorption of C25 Specimens

5. Conclusion

According to the diagrams in Section 4, the following results were obtained by comparing the compressive and tensile strength and water absorption of samples containing flowing sand with the control samples.

A) Compressive strength at the age of 7 days gradually increased by adding desert sand. It reached the highest value for C20 concrete by adding 15% desert sand, showing an almost 20% increase compared the control. Then, with the increase of desert flowing sand, it shows a decrease in compressive strength compared to the maximum obtained. Whereas, a 10% increase in desert sand led to reaching the highest value for C30 and C25 concrete samples. Almost 19% and 14% increase is seen in C25 and C30 classes compared to the control. After that, adding flowing sand leads to decreased compressive strength in comparison with the maximum obtained.

B) Compressive strength at the age of 14 days gradually increased by adding desert sand. It reached the highest value for C20 concrete by adding 15% desert sand, showing an almost 12% increase compared the control. Whereas, a 10% increase in desert sand led to reaching the highest value for C25 concrete sample, which shows a 15% increase compared to the control. For C30, 5% desert sand led to reaching the highest value, showing an almost 17% increase compared the control. After that, adding flowing sand leads to decreased compressive strength so that the compressive strength in 20% sand samples is almost equal to the compressive strength of control samples.

C) Compressive strength at the age of 21 days gradually increased by adding desert sand. It reached the highest value for C20 concrete by adding 10% desert sand, showing an almost 10% increase compared the control; then, with the increase of desert flowing sand, it shows a decrease in compressive strength compared to the maximum obtained. Whereas, a 5% and 10% increase in desert sand led to reaching the highest value for C25 and C30 concrete samples, showing almost 11% and 8% increase compared to the control, respectively. After that, adding flowing sand leads to decreased compressive strength. Strength in 20% sample is almost equal to the compressive strength of control samples.

D) Compressive strength at the age of 28 days gradually increased by adding desert sand. It reached the highest value for C20 concrete by adding 10% desert sand, showing an almost 13% increase compared the control. After that, adding flowing sand leads to decreased compressive strength. Whereas, a 5% increase in desert sand led to reaching the highest value for C25 and C30 concrete samples, showing almost 14% and 11% increase compared to the control for C25 and C30, respectively. After that, adding flowing sand leads to decreased compressive strength. Strength in 20% sample is almost equal to the compressive strength of control samples.

E) In general, the compressive strength gradually increased for C25 and C30 samples. Increasing the flowing sand from 0% to 5% and in some cases 10%, the compressive strength is observed to be more than that of the control. After that, adding flowing sand leads to decreased compressive strength. However, until 15% san, the compressive strength did not experience reduction compared to the control sample. The decrease in compressive strength of the samples can be interpreted as follows; because increasing the amount of sand causes the aggregate to become finer, and on the other hand, the aggregate has a higher specific surface area, more cement is needed. Since the amount of cement in the desired mixtures was considered constant, we encountered a decrease in strength.

F) The tensile strength of C20 at the age of 28 days was higher by 12% than that of the control by adding 10% of flowing sand. For C25 at the age of 28 days, the tensile strength was higher by 18% than that of the control by adding 5% of flowing sand. For C30 at the age of 28 days, the tensile strength was higher by 10% than that of the control by adding 5% of flowing sand. For all classes, the tensile strength was higher than that of the control, meaning the fact that desert sand can improve the tensile strength.

G) By increasing the percentage of desert in the concrete, reduced water absorption was observed. Adding 10% sand led to the lowest water absorption (1.18%). Afterwards, adding sand caused increased water absorption so that 20% sand led to reaching 1.26% water absorption, which is lower than the water absorption of the control.

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