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EXPERIMENTAL ASSESSMENT ON THE USE OF TREATED DESERT SAND AS FINE AGGREGATE TO THE CONCRETE FOR SUSTAINABLE CONSTRUCTION

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Abstract

Seeking new sources of renewable construction materials to address the scarcity of sustainable development is still a challenging matter for scholars in all sectors. One of the best solutions to these challenges is using treated desert sand (TDS) as fine aggregate in concrete production. This study aims to enhance concrete's strength and water absorption using different TDS content. To achieve this aim, five concrete mixtures have been prepared with TDS content of 0, 25, 50, 75, and 100% and show their effect on concrete's density, compressive strength, and water absorption. The study's results explored that using 50% TDS instead of natural aggregate recorded the highest compressive strength of 55.45 MPa at 180 days. While the use of 25% TDS recorded the lowest water absorption of concrete, it is only 3.59%. The results obtained from this study indicate that the addition of TDS has a main effect on the strength and durable concrete especially with 25% and 50% replacement levels. This study recommends to use of large amounts of TDS to address the concrete issues and reduce the cost and environmental issues.

Keywords: Construction materials; Desert sand; Environment; Fine aggregates; Sustainable construction.

1. Introduction

The production of concrete increases day by day without stopping to fulfil the construction market requirements. In addition to that, the Increase of the population requires the construction of new infrastructure projects using huge concrete quantities [1]. In 2015, it produced 8 billion m³ of concrete by using about 5 billion tons of natural sand [2]. Annually, more than 30 billion tons of river sand are consumed, causing the depletion of virgin materials, thus destroying the environment [3, 4]. Also, about 253 million tons of aggregates yearly, are used in Germany [2]. While the consumption of natural fine aggregate is expected around 40 billion tons annually [5].

The extraction rate of mining sand in the Mekong fluvial of Cambodia increased from 24 to 59 million tons between 2016 and 2020, with an increase in the production rate of 8 million tons yearly [6]. To overcome these issues, researchers and academics searched for numerous solutions to detect different materials as fine aggregates to save the virgin materials for the next generations. Many countries do not have natural fine aggregates such as river sand and crushed mining sand, thus importing these aggregates from other countries to fulfil the construction market requirements. Therefore, many investigations were conducted about the potential use of desert sand (DS) as a fine aggregate in concrete mixtures.

On the other hand, there are huge amounts of desert sand spread worldwide [7]. The Earth hosts expansive desert areas, covering approximately 6,000,000 square kilometres, with an abundant reserve of desert sand, as shown in Fig. 1 [8]. Countries in Europe, such as Spain, France, and Germany have large areas covered with desert sand up to 600,000 square miles [9]. China alone has around 1,533,000 square kilometres of desert, while the Thar Desert, India's largest, covers roughly 210,000 square kilometres [10].

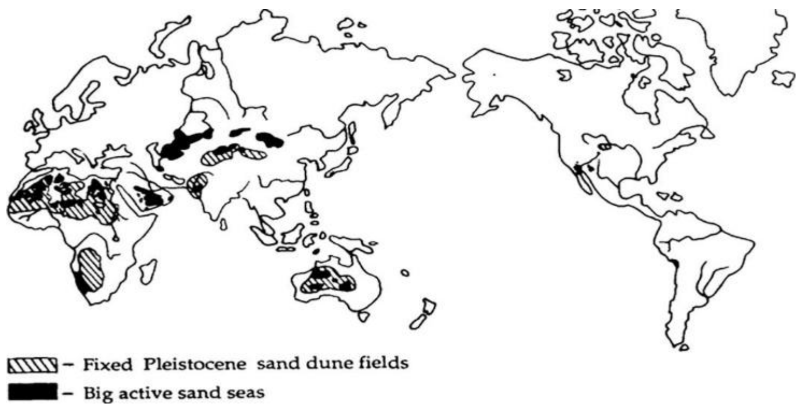

Fig. 1. Distribution of desert areas in the world [8].

However, constructing buildings and infrastructure in these deserts is challenging due to the scarcity of raw materials. Erzaij and Ali [11] reported that the costs of building sand and cement in desert areas are 1.5 times and 1.1 times higher than in other regions, respectively. Consequently, Desert sand's vast reserves and localized abundance present opportunities for its use in construction-based materials (CBMs).

Besides, desert sand as fine aggregate in concrete mixtures releases lower energy consumption and CO_2 emissions than river sand, thus achieving economic benefits. Although, desert sand has numerous benefits available in huge amounts and low cost to use in desert areas with lower transportation costs. However, there are numerous disadvantages like reducing the strength of concrete if it is used in large amounts and has fine particle sizes. Zhang et al. [12] reported that the cost of crushed sand is about $9.27 per ton, while the cost of extracting desert sand is about $6.18 per ton. Therefore, the use of desert sand instead of river sand is considered eco-friendly concrete due to its support of economic and environment.

Especially, the energy consumption values for river sand, crushed sand, and desert sand are recorded at 0.34 MJ/kg, 0.48 MJ/kg, and 0.017 MJ/kg, while the CO_2 emissions for river sand, crushed sand, and desert sand are about 0.024 kg, 0.036 kg, and 0.0013 kg, respectively [13, 14]. DS is primarily composed of SiO_2 and Al_2O_3, and its particles are generally finer than those of river sand.

It is known that only a few studies have been conducted to study the effect of desert sand as a fine aggregate on the strength of concrete [15, 16]. Even though some researchers have studied the use of desert sand as a fine aggregate and its effect on the strength at an early curing age [9]. The use of desert sand as a fine aggregate instead of river and crushed sand in concrete production develops sustainability in the construction sector by reducing energy consumption and environmental pollution. Also, this study searches for the potential use of TDS in construction projects located in most countries that contain huge amounts of desert sand in their deserts. This study offers innovative solutions for sustainable development in different sectors, especially infrastructure projects.

The lack of enough fine aggregate to produce huge amounts of concrete and the lack of studies examining the effect of treated desert sand (TDS) as fine aggregate on the strength and water absorption of concrete at a later age are the main reasons that led to preparing this study. Therefore, this study aims to close this knowledge gap by examining the effect of TDS on the strength and water absorption of concrete at 180 days. To achieve this aim, five concrete mixtures have been prepared with different replacement levels of TDS as fine aggregates of 0, 25, 50, 75, and 100%. The chemical composition and physical properties of natural and desert sand have been examined. Then study of the effect of TDS in different percentages on the density, compressive strength, and water absorption of concrete was conducted.

2. Materials and Methods

2.1. Materials

Ordinary Portland cement (OPC) type I, silica fume (SF), and fly ash (FA) are used as binder materials in the concrete mixtures. Silica fume and fly ash have been used as partial cement replacement in proportions of 8% and 12%, respectively for all concrete mixtures. The addition of silica fume as a partial cement replacement is intended to decrease the negative effect of cement and improve the properties of concrete made of desert sand. The physical properties and chemical composition of Cement, silica fume, and fly ash are listed in Tables 1 and 2, respectively.

Table 1. Physical properties of cement, silica fume, and fly ash.

Properties	Cement	Silica fume	Fly ash
Specific gravity	3.15	2.22	2.19
Fineness-specific surface (m^2/kg)	374	14000	474.2

Table 2. Chemical composition of cement, silica fume, and fly ash.

MATERIAL	SIO_2	AL_2O_3	CAO	FE_2O_3	SO_3	MGO	K_2O	NA_2O	P_2O_5	TIO_2
CEMENT	11.00	2.97	75.65	7.72	0.60	1.0	0.69	0.67	0.399	0.49
SILICA FUME	95.02	---	0.783	0.7	---	---	2.13	---	1.24	---
FLY ASH	52.26	27.33	2.55	9.93	0.047	0.39	2.39	0.21	0.409	4.23

In this study, crushed stone with a maximum particle size of 20 mm was used as coarse aggregate. TDS and mining sand were used as fine aggregates. It is well known that TDS has a finer particle size than mining sand and a high percentage of up to 80% pass over a 0.3 mm sieve, as shown in Fig. 2.

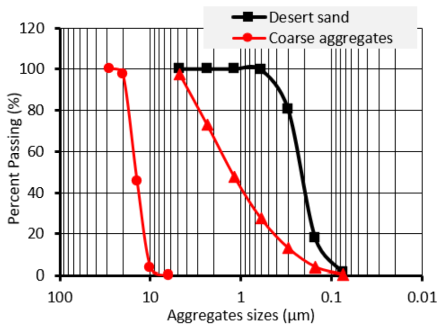

Fig. 2. Distribution curve of fine and coarse aggregates.

TDS particles show both rounded and angular shapes owing to the transport methods they undertake [17]. TDS has a smaller particle size and higher surface area than that found in mining sand. The shape of mining sand and TDS can be observed in Fig. 3(a), while Fig. 3(b) depicts the morphology of desert sand that was obtained using a Scanning electron microscopy (SEM) test.

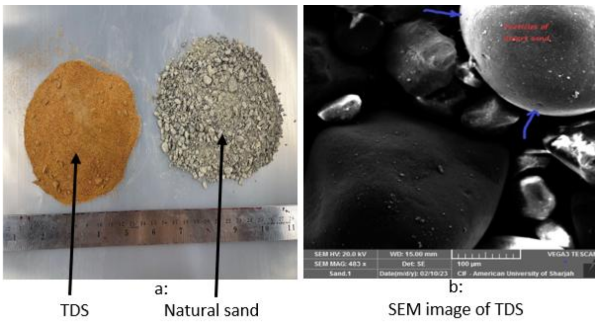

Fig. 3. Physical shapes of (a) TDS and natural sand and (b) SEM image of TDS.

The physical properties of aggregates utilized in this study as shown in Table 3. The Mega flow SP1 with a high water-reducing, was used as a superplasticizer (SP), with a 1% binder materials ratio. The addition of SP is intended to attain appropriate workability and decrease the water-binder ratio in the concrete mix.

To obtain the TDS, the collected desert sand was washed using tap water to eliminate impurities and organic materials. Then, it was exposed to temperatures up to 110 °C using an electric oven for 24 hours.

The available electric oven in the concrete lab was up to 110 ºC. Therefore, it was used to get a saturated-surface-dry (SSD) and disposed of dust grains and organic materials. This treatment has numerous advantages in terms of reducing the organic materials and the carbon content, thus decreasing the carbon dioxide (CO_2). The resulting desert sand from this method is TDS. The chemical composition of raw and treated desert sand was examined using an X-ray fluorescence (XRF) test, as shown in Table 4.

Table 3. Physical properties of the aggregates.

Properties	Natural sand	Desert sand	Coarse aggregate
Particle size (mm)	0.3 – 5	0.1 – 0.4	5 – 20
Apparent density (g/m^3)	2.75	2.58	2.58
Water Absorption (%)	1.4	0.8	1.3
Fineness modulus	2.6	0.43	6.8

Table 4. The chemical composition of raw desert sand (RDS) and TDS was determined using XRF analysis.

Binder materials	SiO_2	Al_2O_3	CaO	Fe_2O_3	K_2O	P_2O_5	TiO_2	MnO
TDS	33.1	4.39	52.75	6.09	2.01	0.409	0.649	0.0227
RDS	22.2	4.24	65.24	5.26	0.998	0.195	1.10	0.032

The properties of desert sand were examined before and after conducting treatment with water and oven drying. There are significant modifications in the chemical composition especially related to the silica and calcium oxides.

The outcomes refer to the silica oxide increased up to 50% due to the process of treated desert sand, while the calcium oxide (CaO) content experienced a notable reduction from 65.24% to 52.75% after subjecting the RDS to water treatment and heating as shown in Table 4. At the same time, the silica oxide (SiO_2) increased from 22.21% to 33.13%. These improvements in the chemical composition of the TDS led to an enhancement in the overall performance of concrete.

2.2. Mix design and preparation of materials

The mixed design was proposed from the trial-and-error method to get the optimum concrete properties. The TDS was used as a replacement of natural sand at different proportions, namely 0, 25, 50, 75, and 100% in the five concrete mixtures named TDS1, TDS2, TDS3, TDS4, and TDS5, respectively, as shown in Table 5. The use of 100% TDS as fine aggregate is to show the effect of TDS as a full replacement of natural sand on the concrete properties.

These concrete samples were prepared to determine the strength and water absorption of concrete at 180 days. The mixing method included the addition of course and fine aggregates, cement, silica fume, and fly ash into the rotating mixer and mixing for about three minutes. Then add half of the water amount gradually, then add the rest of the water with the SP into the mixer and mix for another three minutes. After homogeneous the concrete inside the mixer, the concrete was poured into cubic iron moulds with dimensions of 100 mm3, to determine the density, compressive strength, and water absorption. The concrete samples were left for 24 hours to get dry, then de-moulded and transferred to the water tank for curing purposes.

Table 5. Mix design for concrete mixtures.

Sample code	Basic composition					Additives				
	Cement (kg/m^3)	Silica fume (kg/m^3)	Fly ash (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Desert sand (kg/m^3)	Crushed sand (kg/m^3)	Desert sand (%)	Crushed sand (%)	SP (%)
TDS1	400	40	60	1000	200	0	600	0	100	1
TDS2						150	450	25	75	1
TDS3						300	300	50	50	1
TDS4						450	150	75	25	1
TDS5						600	0	100	0	1

2.3. Testing method

The density of concrete samples was calculated for the concrete age of 180 days according to the specifications suggested by ASTM C642 [18]. The compressive strength testing was performed according to the specifications of (ASTM C39/C39M-17b) [19]. Three concrete cubes were prepared for each concrete mix, to calculate the compressive strength and water absorption at 180 days. The universal machine was used to determine the compressive strength of concrete samples as shown in Fig. 4.

Fig. 4. Machine used for compressive strength test.

3. Results and Discussion

3.1. Influence of TDS on the density of concrete

The use of TDS as a fine aggregate in concrete represents a significant step towards achieving sustainability and reducing CO_2 emissions in the construction industry. The density of concrete plays a critical role in determining the strength and performance of concrete structures. This study investigated the effect of TDS on the density of concrete at 180 days. Desert sand, often overlooked in conventional construction materials, has exclusive features that can considerably affect the density of concrete. This study emphasizes clarifying the complicated interaction between TDS as a fine aggregate and the resultant density of concrete at 180 days. Figure 5 shows the effect of TDS as fine aggregate on the density of concrete at 180 days.

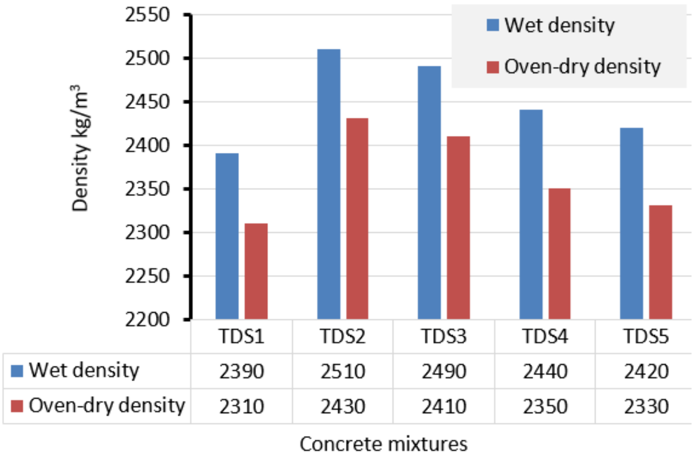

Fig. 5. Wet and oven-dry density of concrete samples.

As illustrated in Fig. 5, the wet density of concrete rose from 2390 kg/m³ for TDS1 to 2510 kg/m³ for TDS2, while the dry density increased from 2310 kg/m³ to 2430 kg/m³ for the same mixtures. This increased density can be attributed to the fact that water-cleaned TDS has fewer soil particles, impurities, salts, and other lightweight organic materials, which influence concrete density.

Treating desert sand with water and oven-drying reduces the presence of lightweight materials within the sand particles. Additionally, the fine particle size of desert sand, with its high surface area, impacts concrete density. The rise in density may also be due to the spherical shape and smoothness of TDS, which help fill the voids between coarse and fine aggregates.

However, concrete density starts to decline when the proportion of desert sand increases significantly, primarily due to decreased flowability in mixtures with a high desert sand content. The density of concrete began to decrease when TDS content exceeded 25%. This finding aligns with the study by Hamada et al. [9], who reported that the reduction in concrete density with high desert sand content is due to the lower specific gravity of desert sand compared to river and crushed sand.

Additionally, Dawood and Jaber [20], who reported that the reduction in concrete density with high desert sand content is due to the lower specific gravity of desert sand compared to river and crushed sand. Table 6 shows the comparison between the previous studies and this study in terms of the effect of desert sand on the density of concrete.

The addition of TDS into the concrete mix led to an increase the density of concrete to be more than that of control concrete for all concrete mixtures. However, the addition of 25% TDS as a fine aggregate recorded the highest density among other concrete mixtures, it was 2510 and 2430 kg/m3 for wet and dry density, respectively. The addition of TDS beyond 25% into concrete mixtures led to a gradual decrease in the density of concrete to 2420 and 2330 kg/m3 for wet and dry density, respectively. However, the density for all concrete mixtures is still higher than that of the control mix. This increase in density can be attributed to the fact that the fine particle sizes of TDS full the voids and pores of concrete mixture as well as the chemical composition of TDS containing a high percentage of silica and alumina oxides.

Table 6. Effect of different sand on the density of concrete.

References	Replacement levels %	Effect on the density
Amhadi and Assaf [21]	0, 20, 30, and 40%	The use of desert sand as fine aggregate increased the density of concrete from 1707.7 to 1832.5 kg/m^3.
Hamada et al. [9]	0, 25, 50, 75, and 100%	The use of desert sand as fine aggregate led to increase the density of concrete from 2226 to 2561 kg/m^3.
This study	0, 25, 50, 75, and 100%	The addition of 25% desert sand led to increase the density from 2310 to 2430 then decrease to the 2330 kg/m^3 due to addition 100% desert sand.

3.2. Influence of TDS on compressive strength

Investigative the compressive strength of concrete is important to evaluating its structural performance [22], and this research investigates the use of TDS as a fine aggregate to enhance the concrete properties at 180 days. Compressive strength is a critical parameter that reflects the ability of concrete to withstand axial loads and external forces, making it a key indicator of the material's strength and durability [23]. The addition of TDS as a fine aggregate in concrete represents a paradigm shift in sustainable construction practices. Figure 6 shows the effect of different proportions of TDS on the compressive strength at 180 curing days.

As shown in Fig. 6, the compressive strength of concrete increased from 46.12 MPa to 54.94 MPa due to the addition of 25% TDS as a fine aggregate into the concrete mixture. Then the compressive strength increased up to 55.45 MPa due to the addition of 50% TDS as a fine aggregate. This increase gradually decreases as the TDS content increases. However, the compressive strengths for all concrete mixtures containing TDS are still higher than that of the control concrete sample by 19.12%, 20.22%, 3.78%, and 0.17%, for the concrete mixtures TDS2, TDS3, TDS4, and TDS5, respectively.

This result agrees with results obtained by Hamada et al. [9], who added desert sand into concrete mixtures as a fine aggregate in different replacement levels. They observed that the addition of 50% desert sand led to obtaining the highest compressive strength at 7, 28, and 56 days. Other researchers found that the use of 20% desert sand as a fine aggregate achieved the maximum compressive strength such as by Lee et al. [24]. Also, Benabed et al. [25] stated that the addition of 25% desert sand as fine aggregate recorded the highest compressive strength, and an increase in the desert sand content of more than 50% leads to reduce the compressive strength of concrete.

The increase in compressive strength of concrete containing TDS might be due to the small particle sizes of TDS, which improve the concrete strength containing TDS due to increased pozzolanic activity [26]. Increased content of TDS beyond

50% has a passive impact on the compressive strength because of the setup of air bubbles. This remark agrees with the outcomes of Guettala et al. [27], they reported that the presence of a small amount of fine particle size of TDS enhances the compressive strength of concrete, while the compressive strength decreases as the fine particle size of TDS increases. Amel et al. [28] observed that the enhanced compressive strength of concrete resulted from the addition of TDS, which has a fine particle size that effectively fills the voids within the desert sand's fine particles. Table 7 shows the comparison between the previous studies and this study in terms of the effect of desert sand on the compressive strength of concrete.

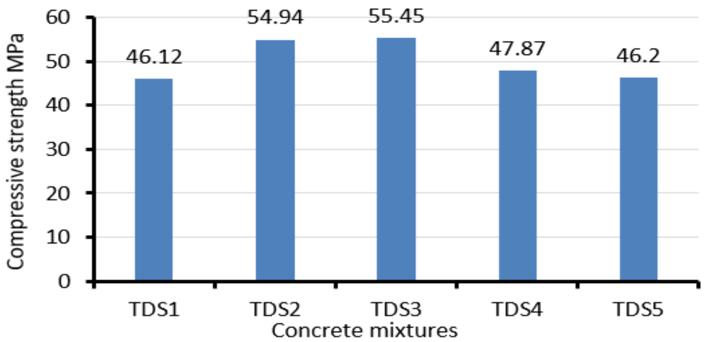

Fig. 6. Compressive strength for concrete mixtures at 180 days.

Table 7. Effect of desert sand on the compressive strength of concrete.

References	Replacement levels %	Effect on the compressive strength
Liu et al. [29]	0, 20, 40, 60, 80, and 100%	The highest compressive strength of concrete was 51.09 MPa, recorded with the addition of 40% desert sand in concrete.
Hamada et al. [9]	0, 25, 50, 75, and 100%	The use of 50% desert sand as fine aggregate increased the compressive strength from 48.7 to 61.06 MPa.
Zhang et al. [15]	0, 20, 40, 60, 80, and 100%	The highest compressive strength of concrete is more than 50 MPa was achieved due to the addition of 20% desert sand as fine aggregate.
Liao et al. [16]	0, 20, 40, 60, 80, and 100%	The use of 40% desert sand as fine aggregate led to an increase compressive strength of concrete up to 40 MPa
This study	0, 25, 50, 75, and 100%	The use of 50% desert sand as fine aggregate led to an increase compressive strength of concrete up to 55.45 MPa

The compressive strength of concrete increases as the TDS content in the concrete mix increases. The compressive strength starts to decrease when the TDS percentage becomes higher than 50%. Yet, the compressive strength of concrete mixtures is still higher than that of the control mix. The concrete mixtures TDS2, TDS3, TDS4, and TDS5 recorded compressive strength higher than that of the control mix by the compressive strength still higher than that of the control concrete sample by 19.12%, 20.22%, 3.78%, and 0.17%, respectively.

This increase in compressive strength of concrete mixtures might be due to the finer particle size of TDS that have lower water absorption and higher specific surface areas and can be used as a filling material to close the voids in the cement matrix. Also, TDS has higher SiO_2, Fe_2O_3, and Al_2O_3, than that of raw desert sand, these three materials are the materials that identify the pozzolanic reaction in the concrete mix. Likewise, Ahmad et al. [30] detected that the compressive strength of concrete increased up to the highest value due to the addition of 40 and 50% desert sand as fine aggregate.

3.3. Influence of TDS on the water absorption of concrete

The assessment of water absorption is an important test in this research, which examines the effect of TDS as a fine aggregate on the concrete at 180 days. Water absorption is a critical parameter in understanding a material's susceptibility to moisture ingress, a factor that significantly influences the durability and long-term performance of concrete structures. This study examines the relationship between the addition of TDS in different replacement levels and the water absorption characteristics of concrete. Fig. 7 shows the relationship between the TDS proportions and water absorption of concrete.

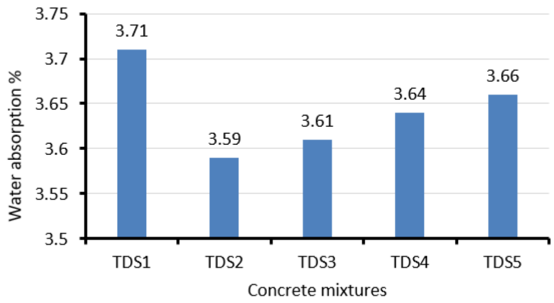

Fig. 7. Water absorption of concrete at 180 days.

As shown in Fig. 7, the addition of TDS as fine aggregate up to 25% into the concrete mix, significantly reduces the water absorption of concrete. The water absorption of concrete mix (TDS2) decreased by 3.23%. TDS2 mix is recorded as having the lowest water absorption rate. While the water absorption of concrete starts to increase when addition TDS as fine aggregate beyond 25%, however, this increase in water absorption is still lower than control concrete with 0% TDS.

The water absorption of concrete decreased by 3.23%, 2.69%, 1.88%, and 1.34% for concrete mixtures TDS2, TDS3, TDS4, and TDS5, respectively. This decrease in water absorption can be attributed to the fine particle sizes of TDS that can fill the pores and voids inside the concrete matrix. Consequently, it is suggested to add TDS with a replacement level of less than 50% to obtain a lower water absorption rate. A similar outcome has been achieved by Dawood and Jaber [20], they reported that the water absorption of concrete decreased to the lowest value due to an increase in desert sand content by up to 40%.

The water absorption of concrete significantly decreased due to the addition of 25% TDS as a fine aggregate into the concrete mix. The decrease in water absorption of concrete might be due to the finer particle size of TDS that act as fill particles and close the voids and pores in the cement matrix, thus getting hardened cement concretes with high strength and durable concrete. The addition of 50, 75, and 100% TDS into concrete mixtures led to an increase in the water absorption of concrete into 3.61, 3.64, and 3.66%. However, the water absorption for all concrete mixtures containing TDS particles is still less than that of control concrete.

4. Conclusions

This paper discusses the effect of treated desert sand as fine aggregate in different replacement levels on the density and strength properties of concrete. According to the results obtained from this study, the following conclusions can be drawn:

- This experimental study is important from an environmental and economic viewpoint, given the huge amounts of desert sand, mainly in the Arabian Gulf countries, Europe, North Africa, and other world countries.
- The addition of TDS as fine aggregate into the concrete mix led to an increase in the wet density of concrete from 2390 to 2510 kg/m^3. However, the increase in TDS content to 100% in concrete mix led to a decrease in the wet density up to 2420 kg/m^3.
- The addition of 50% TDS into concrete mixtures increases the compressive strength of concrete up to 55.45 MPa for the concrete mix TDS3.
- The use of TDS as fine aggregate instead of river and crushed sand mainly contributes to the production of eco-friendly concrete and enhances environmental and economic aspects. Similarly, the use of fly ash and silica fume with high pozzolanic reaction increases the strength of concrete due to containing high silica oxide.

It is recommended to use other SCMs with high content alongside TDS to investigate other concrete properties, such as flexural and tensile strength, as well as the durability properties such as chloride ion penetration, resistance against acid and sulphate, and permeability of concretes. Studying the performance of concrete for long curing age is another important matter that should be considered in future studies to show the effect of alternative materials on the performance of concrete for the long term.

Acknowledgment

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Nomenclatures

ASTM	American Society for Testing and Materials
CaO	Calcium oxide
CO_2	Carbon dioxide
TDS	Treated desert sand
XRF	X-ray fluorescence

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